2.0 Mercury

This chapter briefly discusses mercury sources, cycling, biaccumulation, bioconcentration, ecological risks, human health screening, and the current state of the science in the Northeast. Observed levels of total mercury are compared by Reach with ecological and human health screening criteria and statistically between Reaches. Total mercury concentrations in smallmouth bass, yellow perch and white suckers were significantly higher in upstream Reaches than in downstream Reaches. Mercury poses a risk to recreational and subsistence fishers and to fish-eating wildlife.

2.1 Environmental Sources and Cycling of Mercury

Atmospheric deposition (wet and dry) is a primary source of mercury throughout the Northeast (Figure 2). In the U.S. sources of "airborne mercury include coal-fired power plants, industrial boilers, incinerators and chlorine manufacturing plants. Major water sources include wastewater treatment plants, gold mining operations, landfills and some manufacturing facilities" (Evers 2005; Figure 3). About 60% of northeastern mercury results from U.S. emissions, with total U.S. emissions having declined nearly 50% since 1990 (USEPA 2004). In New England, since the adoption in 1998 of the New England Governor's - Eastern Canadian Premiers Mercury Action Plan (NEG-ECP MAP) it is estimated mercury emissions have declined by about 55% (Smith and Trip 2005).

Mercury cycling in freshwater ecosystems is complex and an area of active research (e.g. Evers 2005). Inorganic mercury may become methylated (organic mercury), de-methylated, absorbed or adsorbed to sediment particles, released by diffusion or resuspension, eaten by organisms or volatilized to the atmosphere. Some water quality parameters, such as dissolved organic carbon (DOC) and pH strongly affect mercury presence in an ecosystem. The USGS (1995) notes that,

> "Studies have shown that for the same species of fish taken from the same region, increasing the acidity of the water (decreasing pH) and/or the DOC content generally results in higher body burdens in fish. Many scientists currently think that higher acidity and DOC levels enhance the mobility of mercury in the environment, thus making it more likely to enter the food chain."

Wiener and Spry (1996) observed:

> "spatial gradients in the mercury content of air and precipitation (Iverfeldt 1991), surface mineral soil and organic litter (Nater and Grigal 1992), lake sediments (Rognerud and Fjeld 1993) and fish (Johansson and others 1991; Lathrop and others 1991; Fjeld and Rognerud 1993) parallel spatial gradients in atmospheric mercury deposition, sulfate deposition, and human activity, indicating a link between mercury deposition and anthropogenic activities."

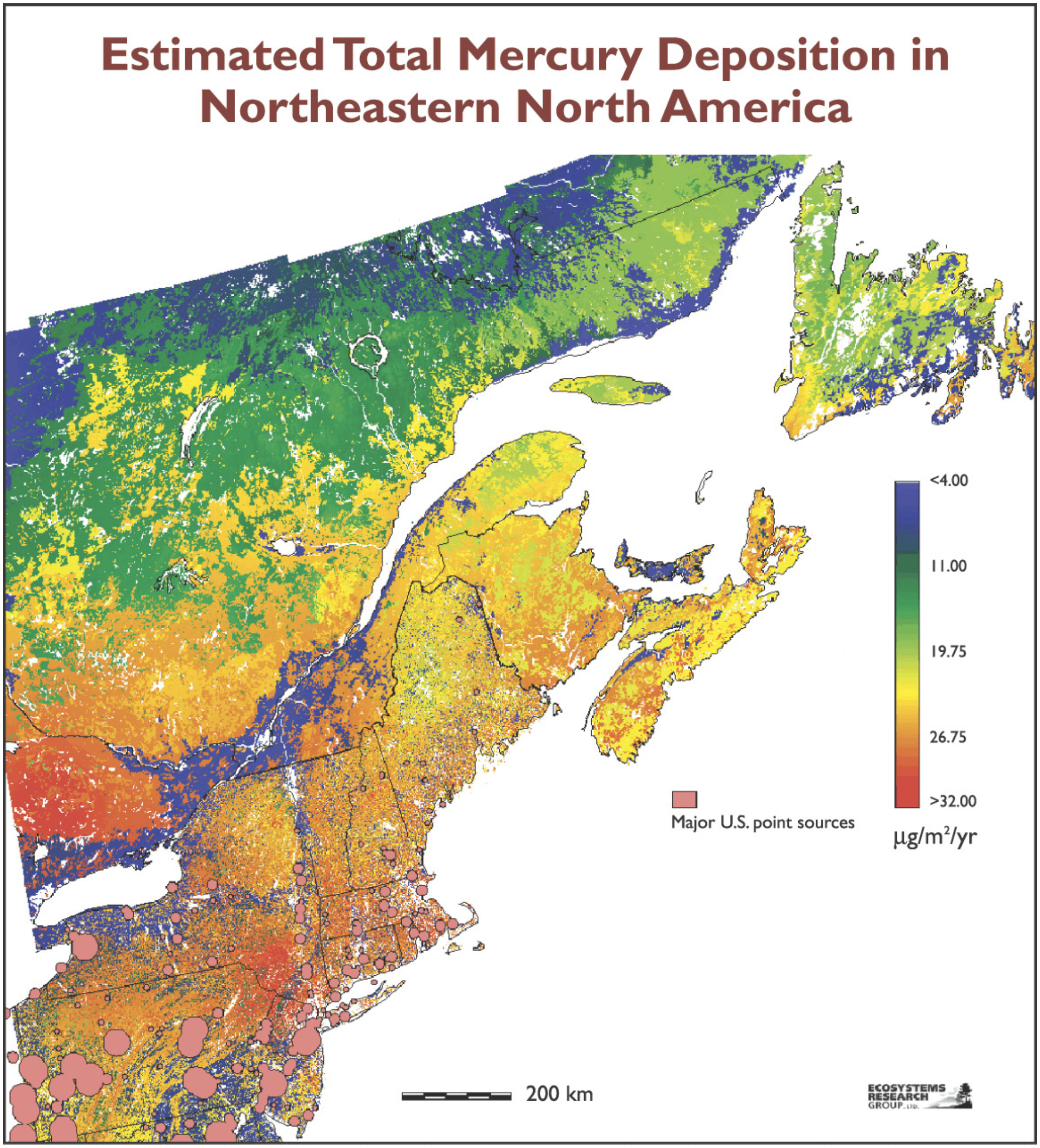

Figure 2. A new model of total mercury deposition to the Northeast. The model is designed to better estimate dry deposition, however, local effects of large point sources are not fully accounted for and are shown in pink (Source: Miller and others 2005).

Figure 4 provides a simplified mercury cycle incorporating both aquatic and terrestrial pathways for bioaccumulation (Evers 2005).

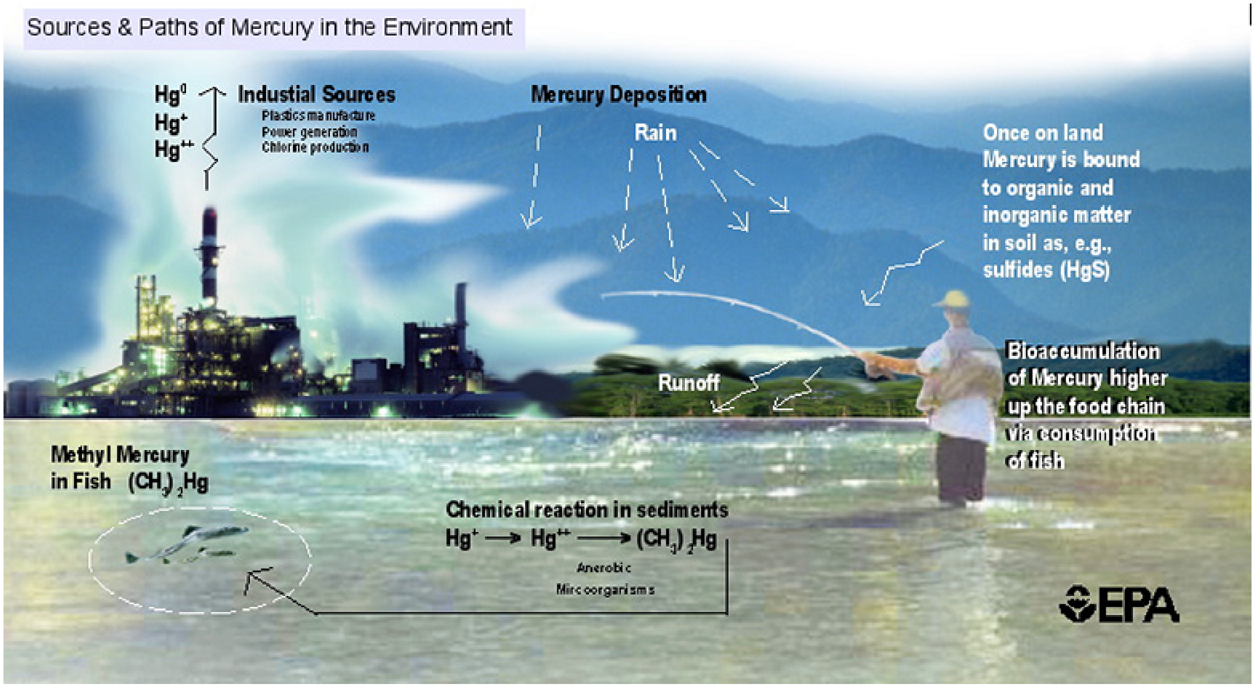

Figure 3. Simplified Freshwater Aquatic Mercury Cycle. Note that non-industrial sources of mercury, including bedrock, are not depicted. Also, atmospheric dry deposition, a significant source of terrestrial and aquatic mercury, is not shown. Terrestrial and marine ecosystem components of the global mercury cycle are also not depicted.

In a national survey of 106 stations from 20 watersheds, including the Connecticut River, for mercury (Hg) and methylmercury (MeHg) in water, sediment, and fish, Brumbaugh and others (2000), reported:

> "Mercury bioaccumulation in fishes was strongly (positively) correlated with the MeHg concentration in water but only moderately with the MeHg in sediment or the total Hg in water. Of the other measured parameters, pH, dissolved organic carbon (DOC), sulfate, sediment loss on ignition (LOI), and the percent wetlands of each basin were also significantly correlated with Hg bioaccumulation in fishes. The best model for predicting Hg bioaccumulation included MeHg in water, pH of the water, % wetlands in the basin, and the acid-volatile sulfide (AVS) content of the sediment."

Ravichandran (2005) in a recent comprehensive review of the relationships between mercury methylation and dissolved organic matter (DOM), noted DOM “interacts very strongly with mercury, affecting its speciation, solubility, mobility, and toxicity in the aquatic environment...[and affecting] the production and bioaccumulation of methylmercury, the most bioaccumulative mercury species in fish."

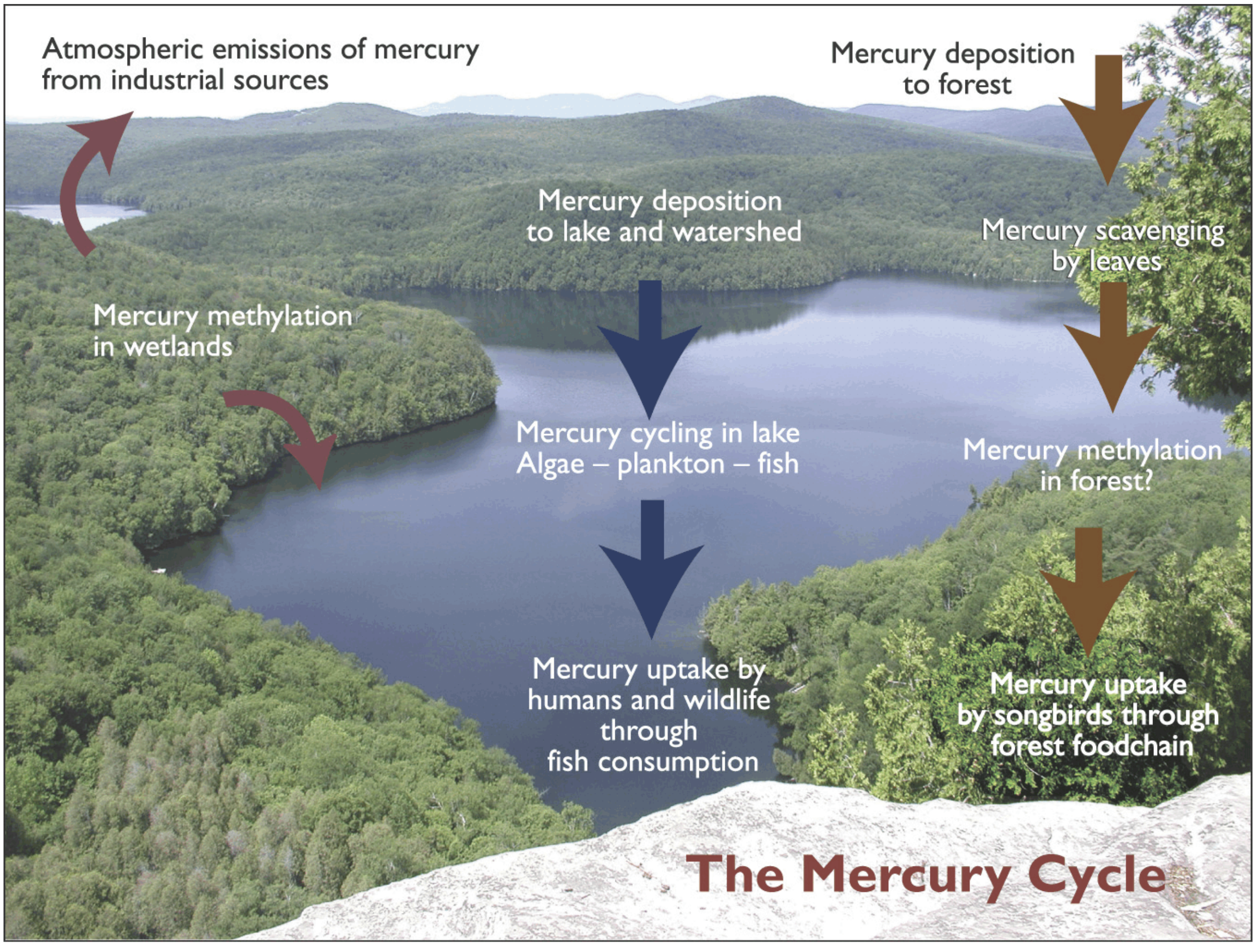

Figure 4. A simplified aquatic and terrestrial mercury cycle (Source: Evers 2005)

The United Nations Global Mercury Assessment (UNEP Chemicals 2002) in citing Ullrich and others (2001) comprehensive review of factors affecting mercury methylation in the aquatic environment notes,

> "Methylmercury can be formed in the environment by microbial metabolism (biotic processes) such as by certain bacteria and by chemical processes that do not involve living organisms (abiotic processes). The formation of methylmercury in aquatic systems is influenced by a wide variety of environmental factors. The efficiency of microbial mercury methylation generally depends on factors such as microbial activity and the concentration of bioavailable mercury (rather than the total mercury pool), which in turn are influenced by parameters such as temperature, pH, redox potential and the presence of inorganic and organic complexing agents."

> "Certain bacteria also demethylate mercury and this tendency increases given increasing levels of methylmercury, thereby forming some natural

> constraints on build-up of methylmercury (Marvin-Dipasquale *and others*, 2000, Bailey *and others*, 2001). Since both methylation and demethylation processes occur, environmental methylmercury concentrations reflect net methylation rather than actual rates of methylmercury synthesis. Numerous bacterial strains capable of demethylating methylmercury are known, including both aerobic and anaerobic species, but demethylation appears to be predominantly accomplished by aerobic organisms. Bacterial demethylation has been demonstrated both in sediments and in the water column of freshwater lakes. Degradation of methyl and phenyl mercury by fresh water algae has also been described."
>
> "Purely chemical methylation of mercury is also possible if suitable methyl donors are present. The relative importance of abiotic versus biotic methylation mechanisms in the natural aquatic environment has not yet been established, but it is generally believed that mercury methylation is predominantly a microbially mediated process."

In aquatic environments the natural levels of mercury depend on complex geological and hydrological characteristics. "Methylation is promoted by environmental factors including increased temperature and chlorides, decreased oxygen, low pH and alkalinity, trophic state, suspended and sedimentary binding substances (e.g. iron, manganese, sulfides, clay), availability of organic compounds (e.g. leaf matter), and existing Hg speciation" (Sweet and Zelikoff 2001).

Sweet and Zelikoff (2001) conclude that:

> "in the aquatic environment, Hg speciation, uptake, bioavailability, and toxicity are dependent upon environmental (e.g. pH, redox state, dissolved oxygen, humic content, selenide and sulfide levels, mineral content, salinity, suspended particles), physicochemical (e.g. solubility, partitioning, metal-ligand complexing, Hg form and content), and biological factors (e.g. presence of methylating or demethylating microbes, receptors, food sources)."

2.2 Ecological Risks of Mercury

Eisler (1987) in a comprehensive review of the ecological effects of mercury on wildlife observed that mercury has no known beneficial biological function and its presence in living organisms is hazardous. Relatively non-toxic forms of mercury can be transformed (methylated) into much more toxic forms, mercury bioconcentrates in organisms through their lifetime and it biomagnifies in food chains to high levels in some fish and wildlife (Figure 6). In humans methylmercury causes mutations of human germ cells, is teratogenic (causes developmental abnormalities), and is a possible carcinogen (USEPA 1997c). Mercury has adverse effects on embryos, cell chemistry and produces disease in tissues; and "the difference between tolerable natural background levels of mercury and harmful effects in the environment is exceptionally small” (Eisler 1987).

"At comparatively low concentrations in birds and mammals, it adversely affects reproduction, growth and development, behavior, blood and serum chemistry, motor coordination, vision, hearing, histology, and metabolism" (Eisler 1987). In teleost (bony) fish the kidney accumulates the highest concentrations of mercury. This is particularly important for potential immunomodulation effects, as the kidney functions as the bone-marrow equivalent in teleosts (Sweet and Zelikoff 2001). Furthermore (Sweet and Zelikoff 2001) note, "there is comparative immunological evidence that fish immune cells and those of higher vertebrates are morphologically, functionally, and biochemically similar." Immunotoxic effects of Hg in fish range from depressed hematopoiesis (blood formation) and enzyme activity to increased apoptosis (cell death). In fish methylmercury is quickly bound to red blood cells and distributed to all organs, including the brain (Wiener and Spry 1996). Ultimately most of the methylmercury is bound to sulfhydryl groups in muscle proteins.

Wiener and Spry (1996) note the neurotoxic effects of methylmercury may adversely affect wild fish's feeding behaviors and ability to avoid predation.

Even low concentrations of mercury will adversely affect "the reproduction, growth, behavior, metabolism, blood chemistry, osmoregulation, and oxygen exchange of marine and freshwater organisms" (Eisler 1987). "At lower trophic levels, the efficiency of mercury transfer was low through natural aquatic food chains; however, in animals of higher trophic levels, such as predatory teleosts and fish-eating birds and mammals, the transfer was markedly amplified" (Eisler 1987).

Laboratory studies have shown that mercury can induce adverse reproductive hormonal effects in fish. Mercury also has been shown, in earlier laboratory studies, “to impair spermatogenesis, decrease gonadosomatic index (GSI), and reduce growth in juvenile fish” (Friedmann and others 2002). However, a preliminary field study by Friedmann and others (1996) was unable to demonstrate adverse reproductive effects among fish populations with four times the U.S. national average mercury concentration.

Whole body concentrations in fish of 1 ppm total mercury (Hg) (wet weight) are believed to not induce chronic toxic effects, whereas concentrations of 10 to 20 ppm are lethal (Sweet and Zelikoff 2001). Fish brain concentrations from 7 to 15 ppm (wet weight) likely produce serious, possibly lethal effects, although susceptibility varies by species (Wiener and Spry 1996). Muscle tissue concentrations from 6 to 20 ppm (wet weight) are indicative of adverse effects. In brook trout whole body concentrations of 5 ppm (wet weight) or greater indicate toxic effects. The NOAEL (no observed adverse effect level) for brook trout is apparently around 3 ppm (wet weight).

Readily observable methylmercury toxic effects in freshwater fish include emaciation, lowered feeding rates, stunted growth, unusual locomotor activity, deformities and possibly darkened skin (Wiener and Spry 1996). They recommend incorporation of such measures into fish-surveillance programs. The current study has examined total mercury and fish condition (Chapter 5). However, Friedmann and others (2002) observed that, “the effect of mercury on the general health of North American fish is not known”.

MeHg in dietary concentrations above 1 ppm was found to be 100% fatal to mink and above 2 ppm was fatal to river otter (Eisler, 1987). "The usually higher mercury concentrations in fish-eating furbearers than in herbivorous species seemed to reflect the amounts of fish and other aquatic organisms in the diet.

Birds are more sensitive than mammals to MeHg, although "[M]ercury toxicity to birds varies with the form of the element, dose, route of administration, species, sex, age, and physiological condition" (Eisler, 1987).

Developing embryos in birds, mammals, and fish are much more sensitive to methylmercury than are adult animals (Wiener and Spry 1996). In fish embryos exposure to small amounts of methymercury is primarily during oogenesis via maternal transmission, an area requiring further study for it's potentially significant effects on fish populations.

Yeardley and others (1998) applied EPA hazard assessment models to derive fish tissue contaminant consumption risk levels for methylmercury for fish-eating mammals (0.1 *u*g/g) and birds (0.02 *u*g/g). They applied these eco-risk screening values[27] to a population of 167 EMAP (Environmental Monitoring and Assessment Program) lakes surveyed in the Northeast from 1992 to 1994. Yeardley and others determined that, respectively, 54% and 98% of fish in surveyed lakes had MeHg values which exceeded wildlife critical values for fish-eating mammals and birds. These screening values for fish-eating mammals (0.1 *u*g/g) and birds (0.02 *u*g/g) will be used in the current study for eco-risk assessment.

In a study cited in USEPA (1997a) of fur-bearers in Wisconsin, mink and otter were found to have the highest concentrations of mercury. Both are summit mammalian predators in the aquatic food chain. Top avian predators and smaller fish-eating birds are also likely to have high mercury body burdens.

EPA is currently conducting research “regarding the distribution and magnitude of mercury across the (Northeast) region and the biological response of loons to this stress. The information on individual loon response will be extrapolated to determine how it effects the loon population (e.g. loon distribution, abundance and growth rates) across the region.” (Evers 2005; Nacci and others 2005).

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[27] The use of the terms ‘screening values’ and ‘screening levels’ in this report are synonymous.

In its Mercury Study Report to Congress USEPA (1997a) notes that it is important to realize that "...broad ecosystem effects of mercury are not completely understood. No applicable studies of the effects of mercury on intact ecosystems were found. Consequently, characterization of risk for non-human species did not attempt to quantify effects of mercury on ecosystems, communities, or species diversity."

A more recent Global Mercury Assessment (UNEP Chemicals 2002) however, concludes, "There are also particularly vulnerable ecosystems and wildlife populations. These include top predators in aquatic food webs (such as fish-eating birds and mammals), Arctic ecosystems, wetlands, tropical ecosystems and soil microbial communities." Sweet and Zelikoff (2001) conclude, "with regard to lower vertebrates and effects susceptibility to Hg, aquatic life at risk to waterborne immunomodulators includes insects, amphibians, fish, marine mammals, and birds." Current Northeast mercury research, summarized by (Evers 2005) has identified particularly vulnerable ecosystem components.

2.3 Mercury in Fish Tissue

Essentially all of the mercury present in fish tissue is methylated (Wiener 1995; Tollefson 1989; USEPA 2000b; NAS 1991). It is covalently bound to sulfhydryl groups in proteins, making a long depuration half-life, on the order of two years (UNEP Chemicals 2002). EPA (2000b) recommends analyzing for total mercury and the conservative assumption be made that all mercury is present as methylmercury. This approach is deemed by EPA to be most protective of human health and most cost-effective and was followed in the current study.

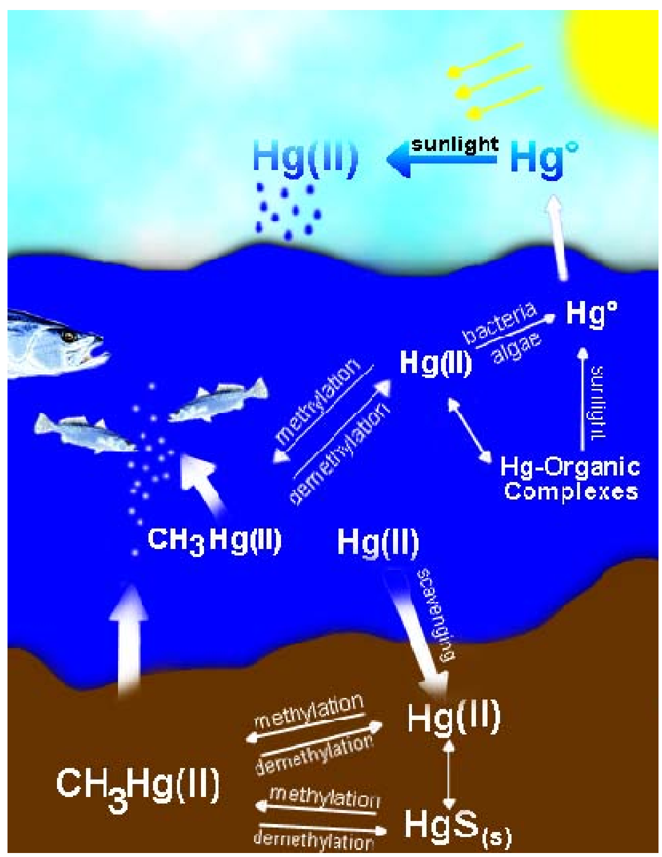

Figure 5. Simplified Pathways of Hg Methylation and Demethylation (Source: Texas A&M University)

While fish are able to methylate small amounts of mercury in the rumen of their gut, most of their MeHg uptake is dietary in origin (Wiener 1995; Wiener and Spry 1996). In temperate waters uptake of mercury is greatest in summer, when feeding rates and methylation processes are highest. The precise mechanisms and pathways of mercury methylation and bioaccumulation are complex and incompletely understood. However, it is known that sulfate (SO_4) processing bacteria can uptake and methylate inorganic mercury. These methylmercury containing bacteria may be eaten by the next organism in the food chain or they may be released to the water and adsorbed to plankton, which may then be consumed (USGS, 1995). Figure 5 shows simplified pathways of mercury methylation, demethylation and uptake in freshwater aquatic environments.

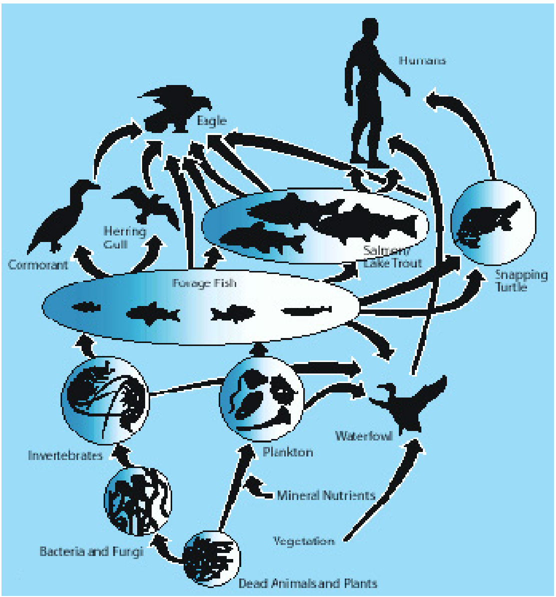

Figure 6. Mercury Aquatic Food Chain (Source: Environment Canada 2001)

Piscivorous (fish-eating) fish typically have higher levels of MeHg. Much of the MeHg accumulates in muscle tissue, which are consumed as fillets. Mercury also accumulates over the life span of fish, thus tending to be higher in older fish. Typically larger fish have higher body burdens of MeHg. Neumann and others (1997) note other factors which affect MeHg levels in fish include "size, age, trophic level and diet, habitat preferences, metabolic rate, growth rate and excretory pathways". Fish bioaccumulate and biomagnify mercury, resulting in much higher concentrations than in their dietary sources. Other factors that affect "the uptake and accumulation of Hg in the aquatic biota include temporal and spatial variation, dominant biotic species (e.g. benthivorous invertebrates, noncarnivorous vs. carnivorous fish" (Sweet and Zelikoff 2001).

The primary human source of methylmercury is through fish consumption (EPA, 2001b; NAS 2000). Figure 6 shows an aquatic mercury food chain with humans at the apex. MeHg is rapidly absorbed into the fetal and adult brain, with the precise mechanism of neurotoxicity undetermined. Adverse human health effects have been observed at increasingly small doses on several organ systems, including the cardiovascular, neurological, immune and reproductive systems, throughout the life span of humans and animals affected by MeHg.

2.4 National Fish Tissue Contaminant Studies

EPA's National Study of Chemical Residues in Fish (USEPA 1992a; 1992b) was a continuation of the the National Contaminant Biomonitoring Program (NCBP) (Schmitt and others 1999). The NCBP was a successor to the National Pesticide Monitoring Program, begun in 1964 to monitor the geographic distribution and concentration through time of organo-chlorine pesticides. Fish have been monitored by the program since 1967. The 1984 version of the NCBP sampled 112 sites for 19 organo-chlorine compounds and 109 sites for 7 metals, including mercury, to include all of the conterminous U.S. major watersheds. One hundred percent of their sampled sites had mercury in fish tissue.

The current four year National Study of Chemical Residues in Lake Fish Tissue (USEPA 2001d) is the:

> "first national fish tissue survey to be based on a probabilistic (random) sampling design, and it will generate data on the largest set of PBT chemicals ever studied in fish. The statistical design of the study will allow EPA to develop national estimates of the mean concentrations of 265 chemicals in fish tissue from lakes and reservoirs of the continental United States. EPA will use the study results to define national background levels for the 265 chemicals in fish, to establish a baseline to track progress of pollution control activities, and to identify areas where contaminant levels are high enough to warrant further investigation."

The first year's (1999-2000) sampling results found mercury in 139 of 143 fish samples, with concentrations ranging from 0.023 to 1.377 ppm wet weight (USEPA 2001d). The data from the first year of this national study is available in USEPA (2002c).

Other studies have documented mercury concentrations in fish in mercury contaminated environments, such as by chloralkali plants, pulp and paper mills and other industrial discharges frequently ranging from 1-10 ppm wet weight, with mean concentrations in piscivorous fish in these waters ranging from 1-7 ppm wet weight (USEPA 1995; Wiener and Spry 1996).

2.5 EPA's Mercury Study Report to Congress

EPA's White Paper, which summarizes findings of the comprehensive eight volume December, 1997 Mercury Study Report to Congress (http://www.epa.gov/mercury/report.htm) observes that,

> "Mercury is the most frequent basis for fish advisories, represented in 60% of all water bodies with advisories. Advisories for mercury are increasing faster than for any other pollutant. They increased 28% from 1995 to 1996 (from 1,308 to 1,675). Thirty-nine states have advisories for mercury in one or more water bodies, and nine States have issued statewide mercury advisories.[28]
>
> "The magnitude of exposure to mercury (especially methylmercury) and degree of risk from fish consumption depends on two things: the level of mercury in the fish consumed and the amount of fish an individual

[28] Advisories for mercury increased by 222 in 2003. Forty-five states issued mercury advisories in 2003 (USEPA 2004).

consumes. People who consume average amounts of a variety of commercially available fish as part of a balanced diet are not likely to consume harmful amounts of mercury. Moreover, fish is an excellent source of proteins, vitamins and minerals and including a variety of fish in the diet is a healthy dietary practice.

"The greatest exposure and risk exist for those persons who regularly eat large amounts of fish from a single location which has been impacted by mercury pollution, particularly for women of childbearing age, because the fetal nervous system is more sensitive to mercury toxicity than is that of adults. Everyone, including pregnant and childbearing-age women, should follow established guidelines in accordance with existing state and tribal advisories on locally caught fish in order to obtain the benefits of fish consumption while reducing the potential risk of mercury exposure."

Volume VI of EPA's Mercury Study Report to Congress (USEPA 1997d) provided a methylmercury criterion for protection of piscivorous wildlife species of 0.08 ppm, in fish of trophic level 3, and 0.35 ppm, in trophic level 4 fish. This range supports the validity of the wildlife screening criteria used in the current study, as smallmouth bass and white sucker adults have a trophic level of ~3 and yellow perch juveniles and adults have a trophic level of ~4.

2.6 EPA's Human Health Screening Values for Mercury

As medical knowledge has grown the harmful effects of levels of mercury once considered safe by health experts have become apparent. Dr. Charles C. Edwards, Jr. Federal Commissioner of Food and Drugs in the December 20, 1970 New York Times stated that fish with total mercury levels above 0.5 ppm were "absolutely" safe to eat. He is quoted as saying "The guideline offers a substantial margin of safety" and should not be regarded as an absolute tolerance level (cited in Houghton, 1971)[29]. Dr. Kathyrn Mahaffey (2004), a noted EPA mercury expert, estimated over 600,000 U.S. newborns each year were at risk for nervous system effects from methylmercury exposure in the womb. Based on a review of all four years (1999-2002) of the CDC (Centers for Disease Control and Prevention) NHANES (National Health and Nutrition Examination Survey) data she has revised this number to an estimated 410,000 U.S. newborns at risk from maternal mercury (Mahaffey 2005).

EPA (2000a) has established screening values for many contaminants in fish tissue which are intended to be default values when site-specific consumption information for

[29]Montague (2006) provides a chilling historical account of the growing public and governmental awareness of the threat of mercury.

recreational (sport) or subsistence fishers[30] is unavailable. For MeHg, noncarcinogen screening values for recreational fishers are 0.4 ppm Hg - wet weight and for subsistence fishers they are 0.049 ppm Hg - wet weight. These screening values are based on a reference dose of 1×10^{-4} (mg/kg-d)[31]. These screening values (SVs) are used in the following human health risk screening Figures. EPA (2000a) advises that "[E]xceedance of these SVs should be taken as an indication that more intensive site-specific monitoring and/or evaluation of human health risks should be conducted."

Table 9 shows the EPA recommended monthly fish consumption limits based on fish tissue mercury concentration in ppm - wet weight.[32]

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[30] "Sport fishers include all noncommercial fishers who are not subsistence fishers. (They have also been referred to as recreational fishers.)" (EPA 2000b). EPA (2000b) currently recommends default fish consumption rates of 17.5 g/d for recreational (sport) fishers. "...subsistence fishers are defined as fishers who rely on noncommercially caught fish and shellfish as a major source of protein in their diets...Native American subsistence fishers are a unique subsistence fisher population that needs to be considered separately" (USEPA 2000b). EPA currently recommends default fish consumption rates of 142.4 g/d for subsistence fishers. "Multiple contaminant exposure is significant for Native American subsistence fishers. A large number of contaminants are often detected in fish tissues and their combined risk associated with the higher consumption rates and dietary preferences for certain fish parts could be very high even if individual contaminants do not exceed the EPA reference dose" (Harper and Harris 1999).

[31] EPA's methylmercury reference dose is a Benchmark Dose (BMD) and not a LOAEL or NOAEL (see Definitions - Chapter 8). Rather it is "a dose that produces a predetermined change in response rate of an adverse effect compared to background" (Mahaffey 2005).

[32] The Centers for Disease Control and Prevention (CDC) Third National Report on Human Exposure to Environmental Chemicals (2005) provides "the most extensive assessment ever made of the exposure of the U.S. population to chemicals in our environment" including all contaminants assessed in the current study (http://www.cdc.gov/exposurereport/3rd/default.htm).

Table 9. Monthly Fish Consumption Limits for Noncarcinogenic Health Endpoint - Methylmercury (Source: USEPA 2000b).

Risk Based Consumption Limit[a]	Noncancer Health Endpoints[b]
Fish Meals/Month	Fish Tissue Concentrations (*ppm, wet weight*)
Unrestricted (>16)	0 - 0.029
16	>0.029 - 0.059
12	>0.059 - 0.078
8	>0.078 - 0.12
4	>0.12 - 0.23
3	>0.23 - 0.31
2	>0.31 - 0.47
1	>0.47 - 0.94
0.5	>0.94 - 1.9
None (<0.5)	>1.9

a The assumed meal size is 8 oz (0.227 kg). The ranges of chemical concentrations presented are conservative, e.g., the 12-meal-per-month levels represent the concentrations associated with 12 to 15.9 meals.
b Chronic, systemic effects.

Notes on Table 9:

1. Consumption limits are based on an adult body weight of 70 kg and an interim RfD of 1×10^{-4} mg/kg-d.
2. None = No consumption recommended.
3. In cases where >16 meals per month are consumed, refer to Equations 3-1 and 3-2, Section 3.2.1.2, for methods to determine safe consumption limits.
4. The detection limit for methylmercury is 1×10^{-3} mg/kg.
5. Instructions for modifying the variables in this table are found in Section 3.3.
6. Monthly limits are based on the total dose allowable over a 1-month period (based on the RfD). When the monthly limit is consumed in less than 1 month (e.g., in a few large meals), the daily dose may exceed the RfD.

2.7 EPA's Water Quality Criterion for Methylmercury

In January, 2001 EPA published the final version of a human health Ambient Water Quality Criterion (AWQC) for methylmercury in fish tissue of 0.3 ppm wet weight. (U.S. EPA 2001b), replacing the AWQC for total mercury published in 1980, which was partially updated in 1997. This criterion is used as a human health screening value. U.S. EPA (2001a) notes:

> "This water quality criterion describes the maximum advisable concentration of methylmercury in freshwater and estuarine fish and shellfish tissue to protect consumers of fish and shellfish among the general population. EPA expects the criterion recommendation to be used as guidance by States, authorized Tribes, and EPA in establishing or updating water quality standards for waters of the United States. Because consumption of contaminated fish and shellfish is the primary route of human exposure to methylmercury, EPA is expressing this water quality criterion as a fish and shellfish tissue value rather than as a water column value....Human health water quality criteria are numeric values we believe will protect human health for pollutant concentrations in aquatic media, such as ambient waters and edible tissue.
>
> "EPA publishes water quality criteria under the authority of Section 304(a) of the Clean Water Act (CWA) based solely on data and scientific judgments about the relationship between pollutant concentrations and environmental and human health effects. CWA Section 303(c) and its implementing regulations require states and authorized tribes to adopt water quality criteria to protect designated uses in their water quality standards. EPA's recommended Section 304(a) water quality criteria may guide States and authorized Tribes in establishing water quality standards. The resulting standards may serve as a basis for controlling discharges or releases of pollutants. EPA's recommended human health water quality criteria are not regulations themselves, and do not impose legally binding requirements. EPA may change the section 304(a) water quality criteria in the future."

Table 10 summarizes the human health and eco-risk screening criteria used in the current study and graphically depicted in Section 2.9

Table 10. Mercury Human Health and Eco-Risk Screening Criteria

Human Health Criteria (ppm)			Eco-Risk Criteria (ppm)	
Recreational/ Sport Fishers	Subsistence Fishers	Water Quality Criterion	Fish-eating Birds	Fish-eating Mammals
0.4	0.049	0.3	0.02	0.1

2.8 Current State of Mercury Science in the Northeast

The Biodiversity Research Institute in Maine in March 2005 published *Mercury Connections - The extent and effects of mercury pollution in northeastern North America* (http://www.briloon.org/mercury/index.htm)(Evers 2005). This document summarizes the major findings of a series of 21 papers that were published in Ecotoxicology (Evers and Clair 2005). The full text of these papers is provided by Springer Verlag at the Ecotoxicology website in the link to Volume 14, Issues 1 and 2: (http://www.springerlink.com/openurl.asp?genre=journal&issn=0963-9292)

Evers (2005) concludes that mercury should no longer be considered a strictly aquatic pollutant. Mercury pollution is pervasive across the landscape affecting even high elevation terrestrial forest ecosystems and headwater streams. Biological hotspots can occur in sensitive environments "where conditions are conducive to methylmercury production or the build-up of mercury in the food chain". Watershed characteristics can be as important as mercury loading in determining mercury sensitivity. There is a need for enhanced mercury monitoring to protect human health and fish and wildlife populations.

Evers (2005) has compiled more recent information on the effects of mercury on fish, birds, mink and otter (adapted from Chan and others 2003). Evers (2005) notes a threshold level for identifying potential fish 'hotspots' is a whole fish concentration of 0.16 ppm (wet weight), as this level can pose population level risk for fish-eating birds, such as common loons. This value relates to loon-size fish, smaller than most of the fish sampled in the current study.

Kamman and others (2005) observe that length standardized (5.0 in.; 12.7 cm.) yellow perch from 42 percent of sampled Northeastern waters had average fish mercury concentrations exceeding the U.S. Environmental Protection Agency (EPA) Water Quality Criterion of 0.3 ppm in fillets. In fact, the average region-wide mercury concentrations in most fish species exceeded this criterion.

2.9 Total Mercury by Reach and Species - Human Health and Eco-Risk Screening

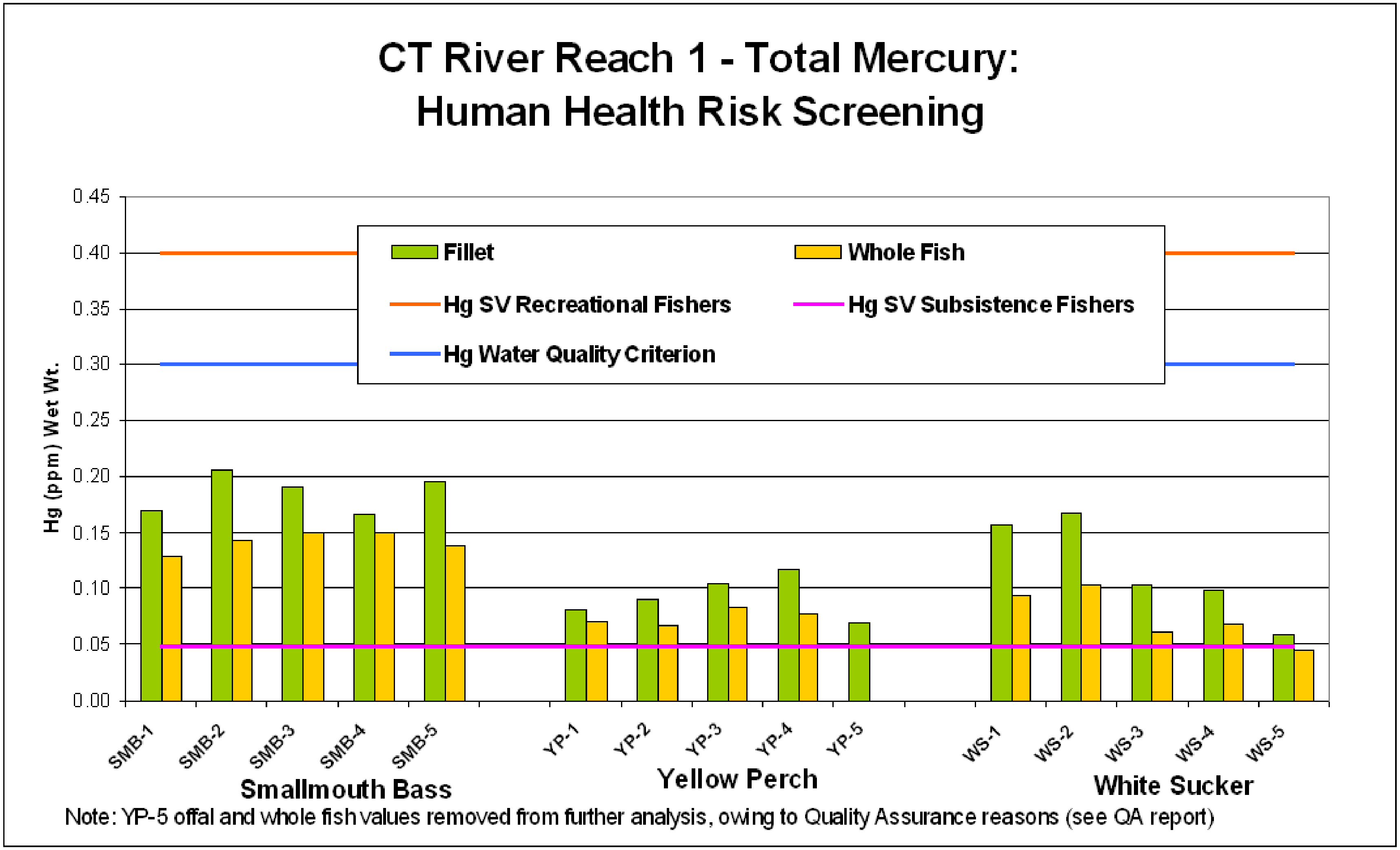

Figure 7. CT River Reach 1 - Total Mercury: Human Health Risk Screening

Total mercury in Reach 1 in all species and samples was below both the non-carcinogenic screening value (SV) for recreational fishers (0.40 ppm) and the methyl-mercury water quality criterion (0.30 ppm) (MeHg-WQC) (Figure 7; Tables 11 and 12). However, all species and samples, either approached or exceeded the SV (0.049 ppm) for subsistence fishers.

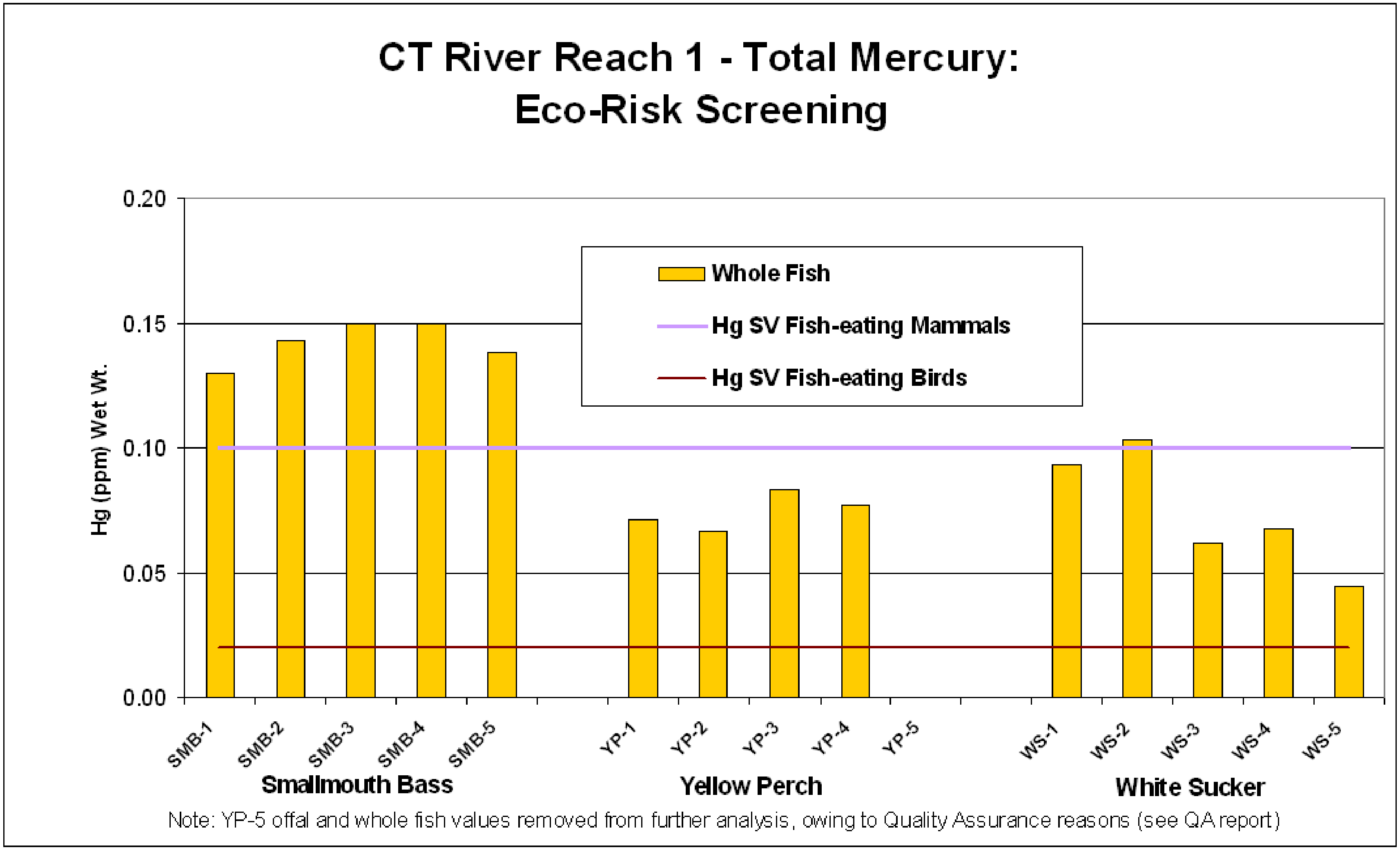

Figure 8. CT River Reach 1 - Total Mercury: Eco-Risk Screening

All smallmouth bass composites exceeded ecological screening values for both fish-eating birds (0.02 ppm) and mammals (0.1 ppm) (Figure 8; Tables 11 and 12). Yellow perch only exceeded eco-risk criteria for birds. Only one of five white sucker composites equalled or exceeded the SV for fish-eating mammals, whereas all five white sucker composites exceeded the SV for fish-eating birds.

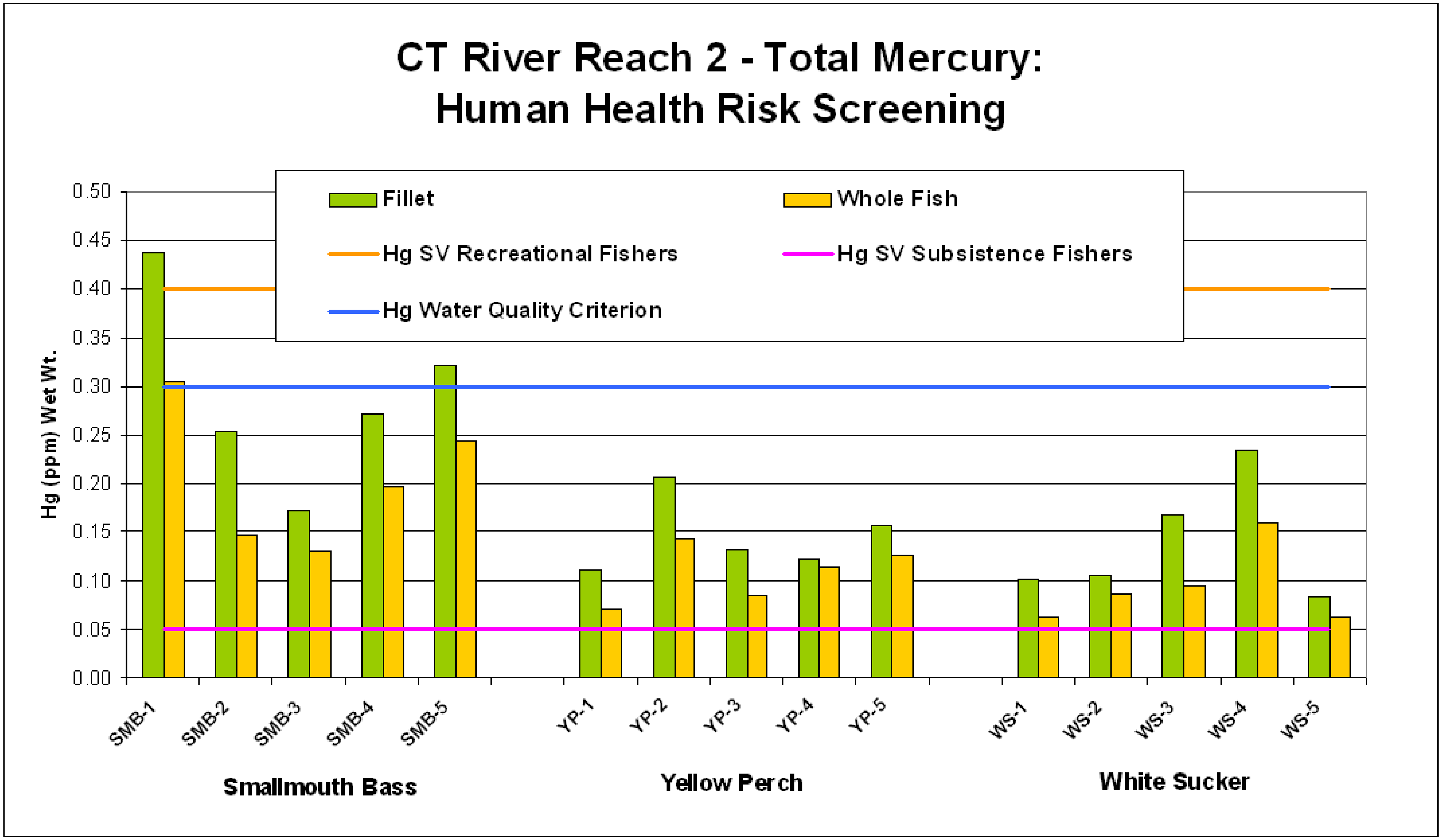

Figure 9. CT River Reach 2 - Total Mercury: Human Health Risk Screening

Total mercury in Reach 2 in smallmouth bass fillets of SMB-1 exceeded the SV for recreational fishers and in SMB-1 and SMB-5 the MeHg-WQC (Figure 9; Tables 11 and 12). All species and samples exceeded the SV for subsistence fishers.

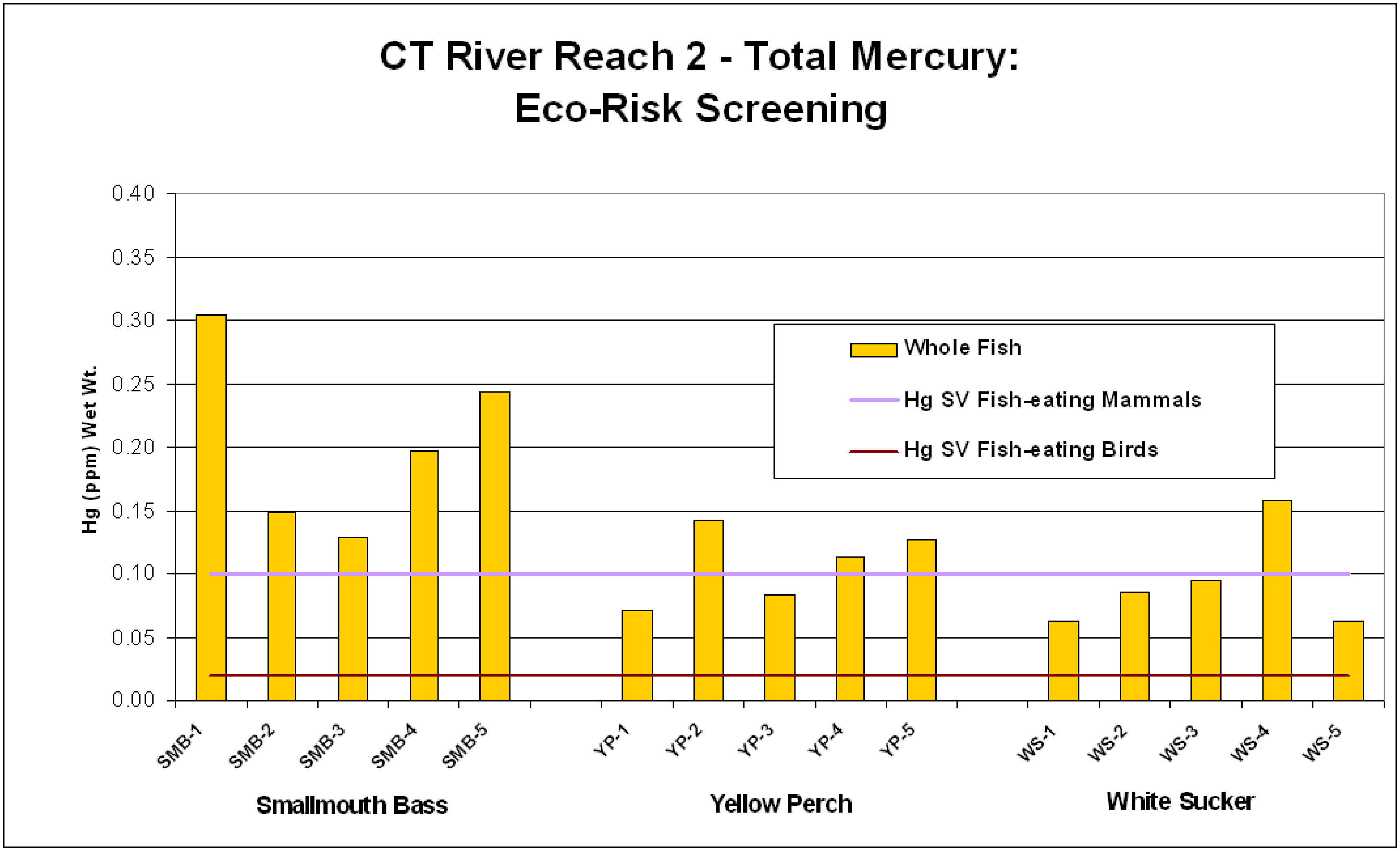

Figure 10. CT River Reach 2 - Total Mercury: Eco-Risk Screening

All smallmouth bass, three yellow perch, and two white suckers exceeded the screening value for fish-eating mammals. All samples in all species exceeded the SV for fish-eating birds (Figure 10; Tables 11 and 12).

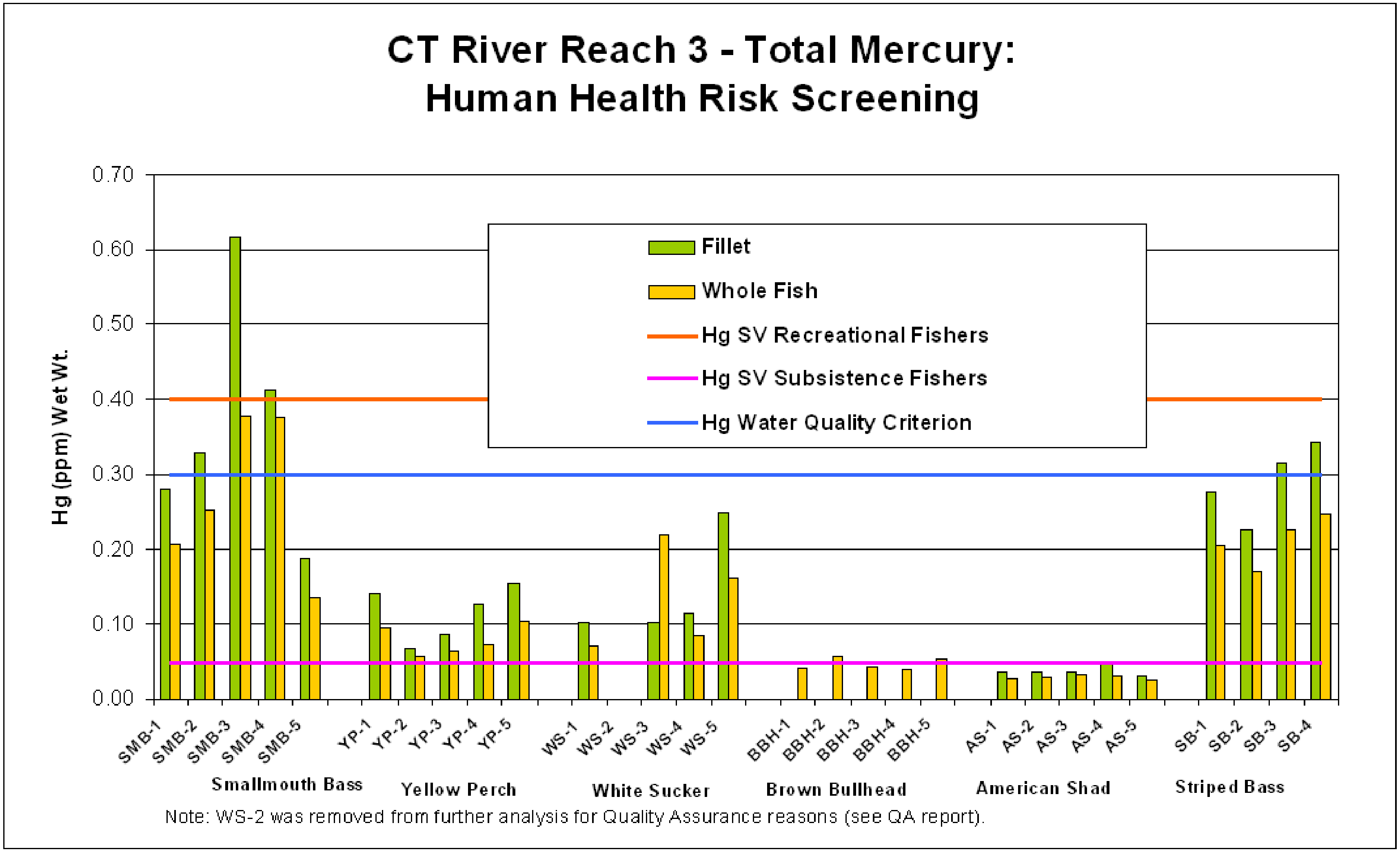

Figure 11. CT River Reach 3 - Total Mercury: Human Health Risk Screening

Total mercury in Reach 3 in all species and samples, except for SMB-3 and SMB-4, was below the SV for recreational fishers. SMB-2, SMB-3, SMB-4, SB-3 and SB-4 all exceeded the MeHg-WQC. All samples for smallmouth bass, yellow perch, white suckers, and striped bass approached or exceeded the SV for subsistence fishers. Brown bullhead and American shad samples were either just above or somewhat below the SV for subsistence fishers (Figure 11; Tables 11 and 12).

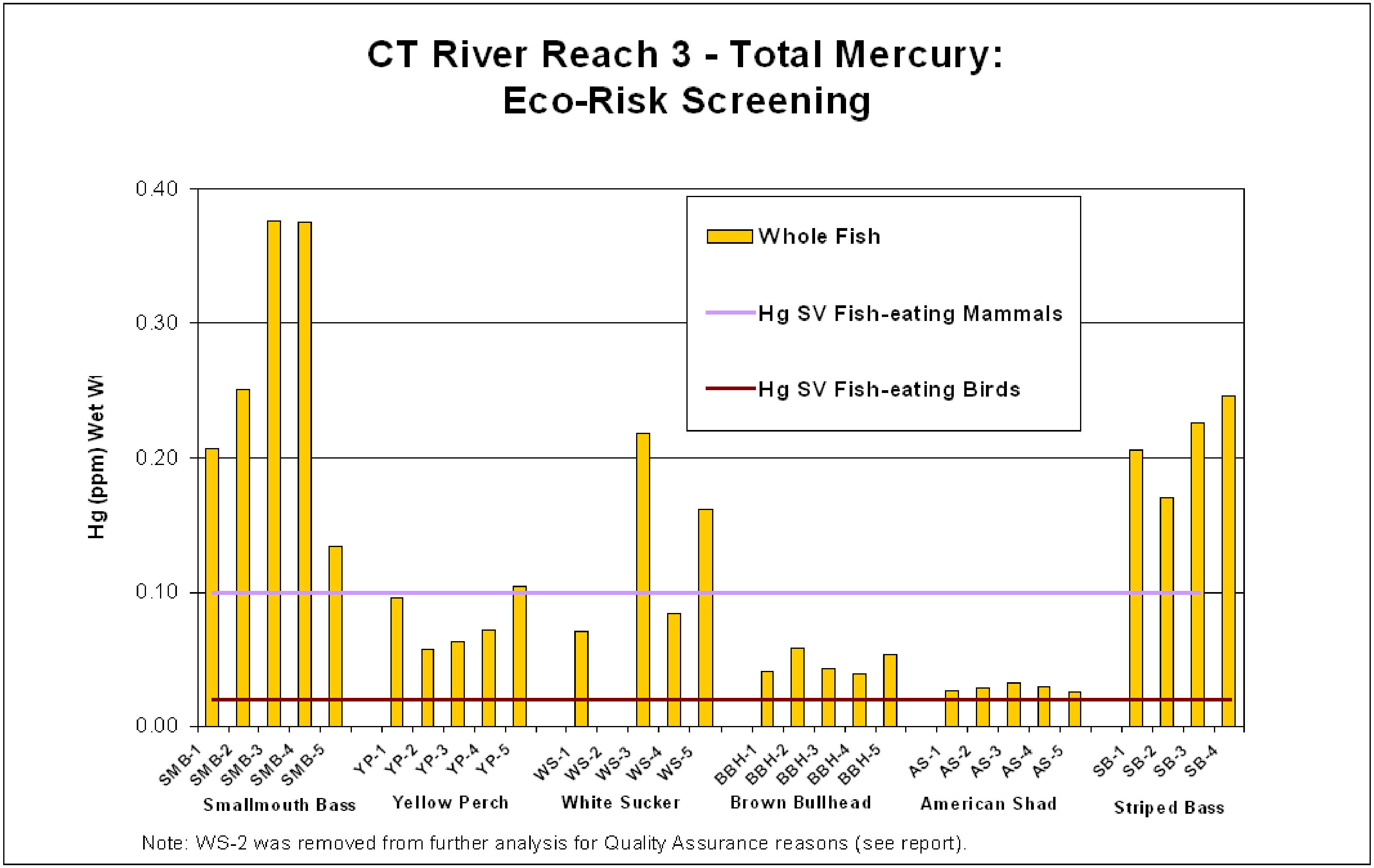

Figure 12. CT River Reach 3 - Total Mercury: Eco-Risk Screening

All smallmouth bass, two yellow perch, two white suckers, and all four striped bass samples exceeded the SV for fisheating mammals. All samples for all species exceeded the SV for fish-eating birds (Figure 12; Tables 11 and 12).

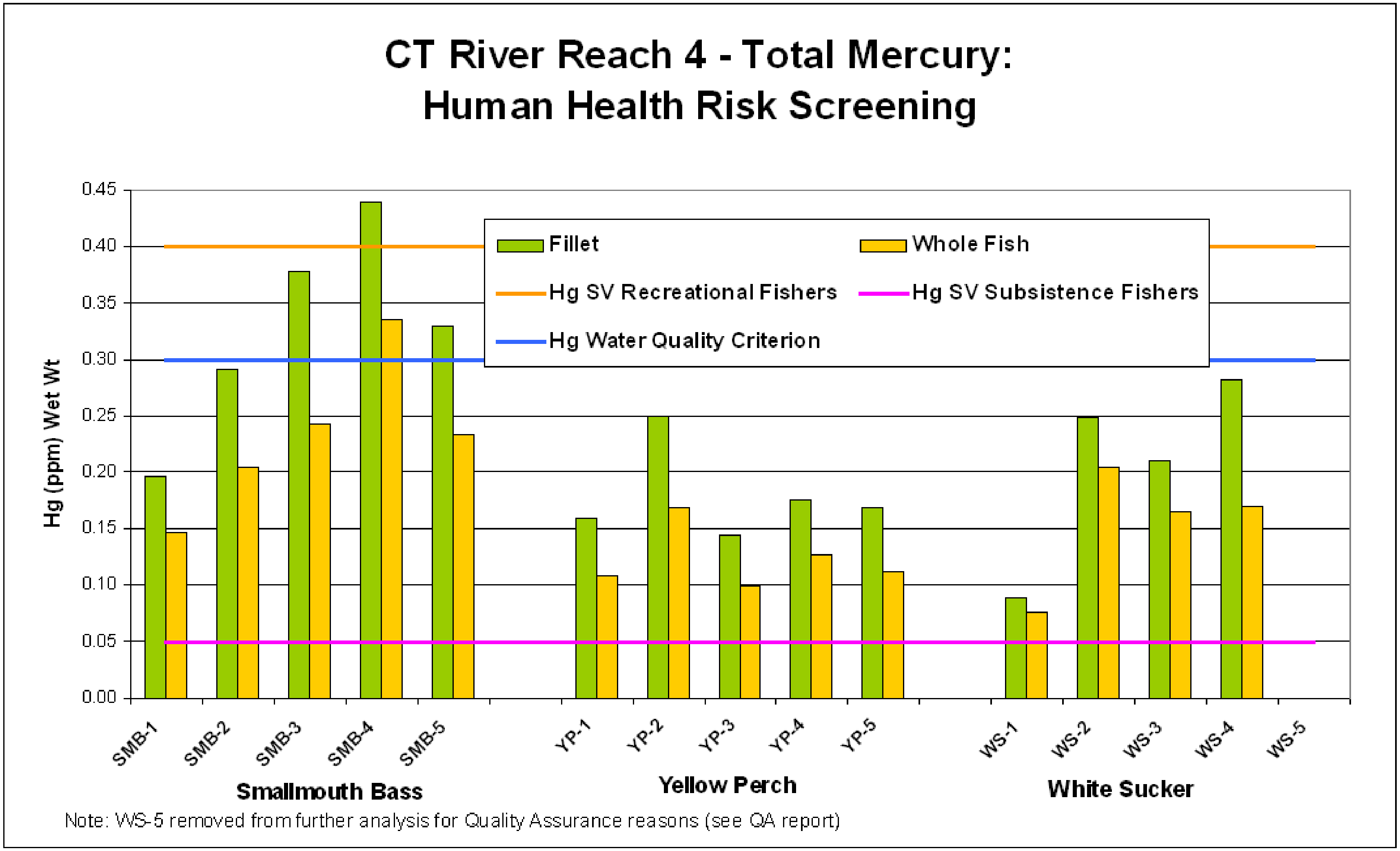

Figure 13. CT River Reach 4 - Total Mercury: Human Health Risk Screening

Total mercury in Reach 4 smallmouth bass fillets of composite SMB-4 exceeded the SV for recreational fishers and in SMB-3 and SMB-5 exceeded the MeHg-WQC. All species and samples, exceeded the SV for subsistence fishers (Figure 13; Tables 11 and 12).

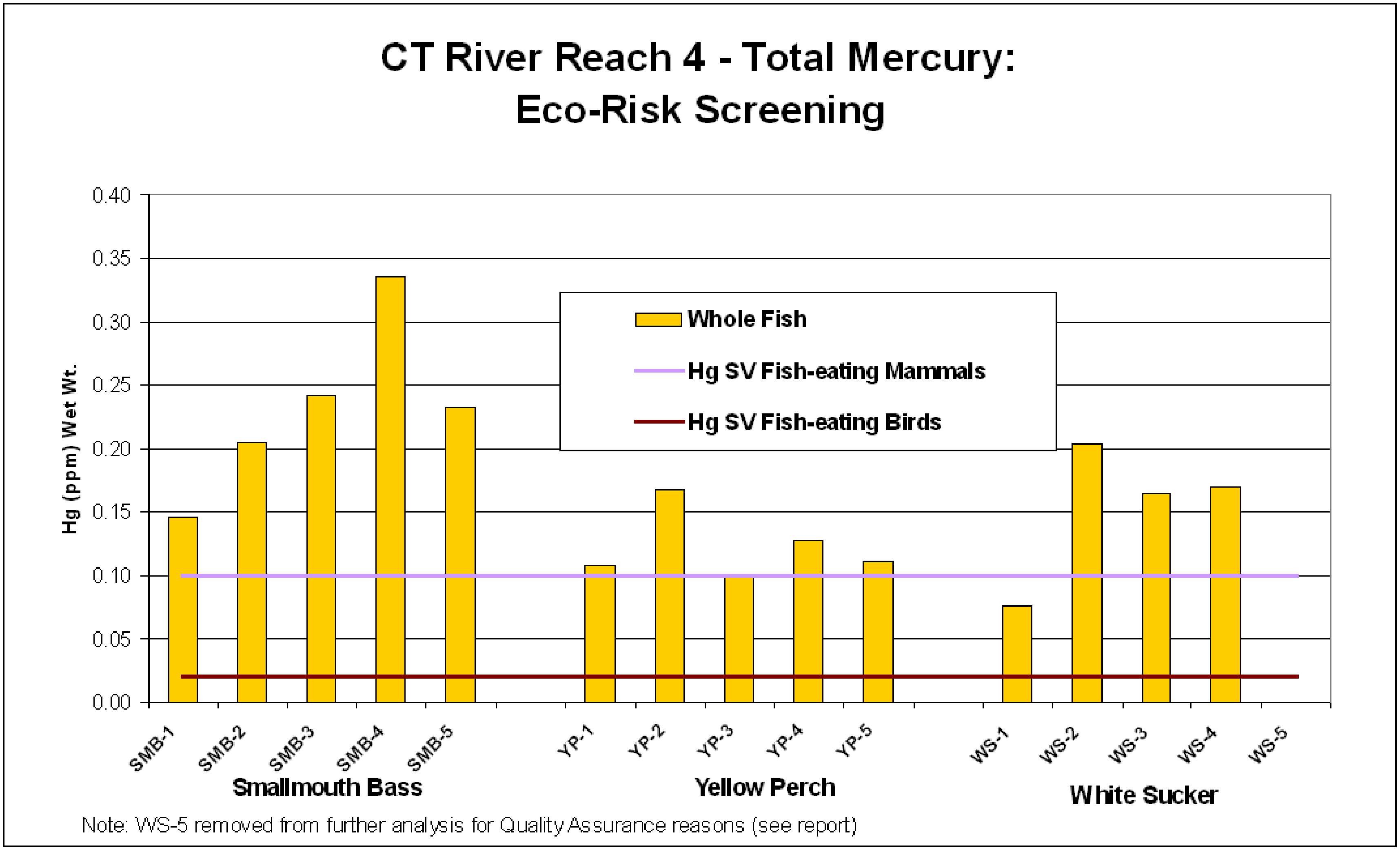

Figure 14. CT River Reach 4 - Total Mercury: Eco-Risk Screening

All species and composites exceeded the eco-risk screening value for fish-eating birds in Reach 4. All species and composites, with the exception of one white sucker composite, exceeded the eco-risk screening value for fish-eating mammals (Figure 14; Tables 11 and 12).

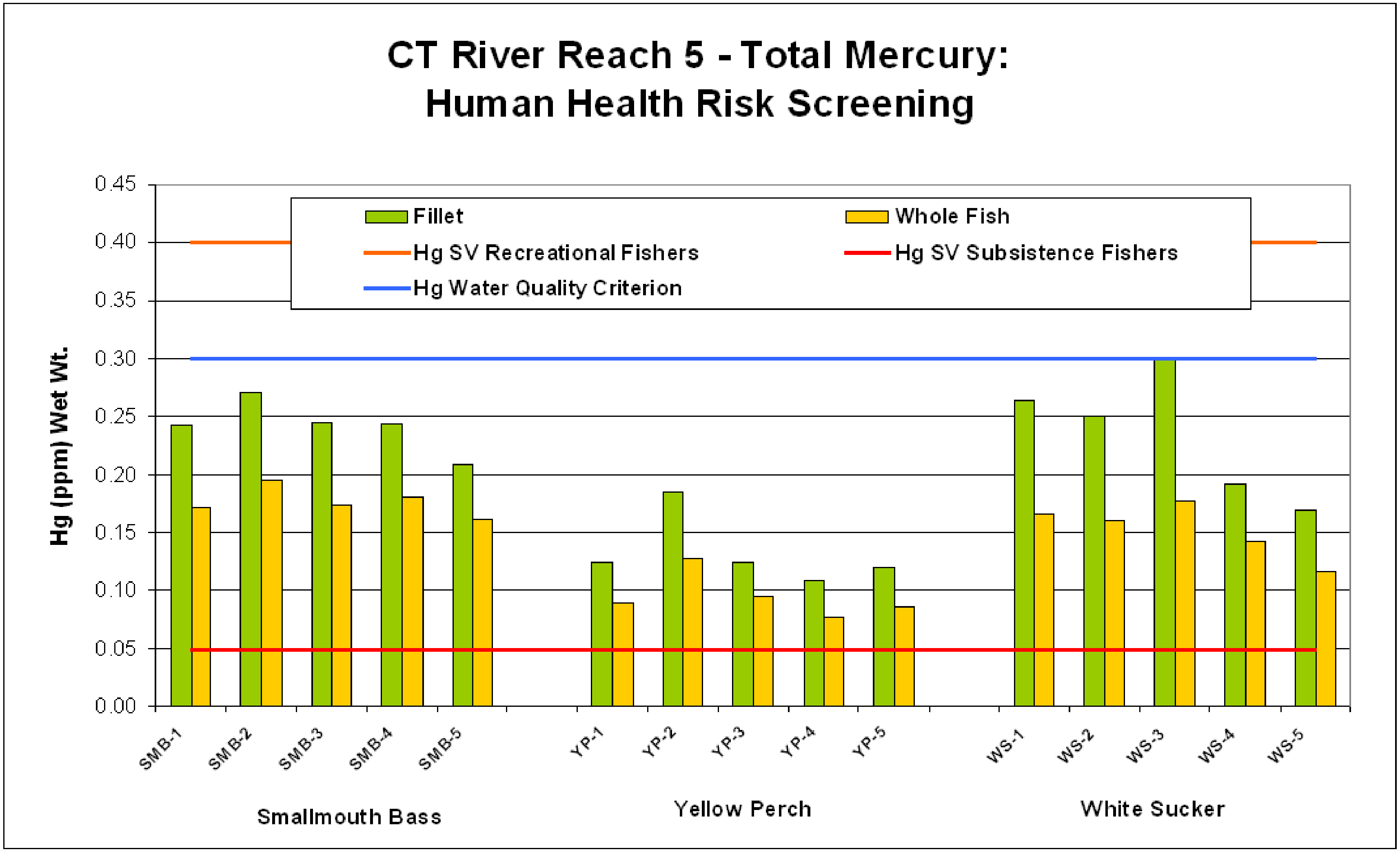

Figure 15. CT River Reach 5 - Total Mercury: Human Health Risk Screening

Total mercury in Reach 5 in all species and samples was below the SV for recreational fishers. All samples, except for the WS-3 fillet were below the MeHg-WQC. All species and samples, exceeded the SV for subsistence fishers (Figure 15; Tables 11 and 12).

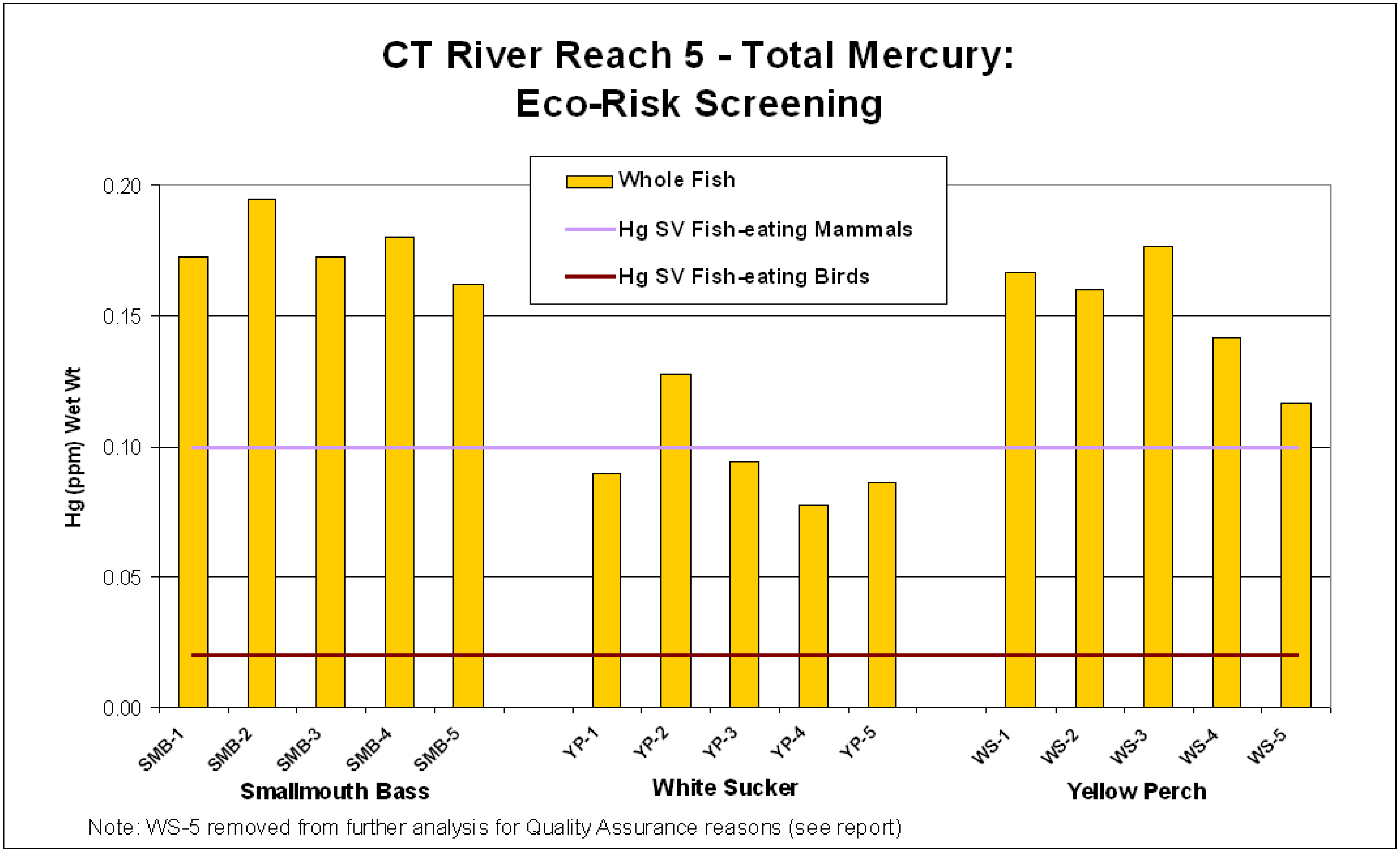

Figure 16. CT River Reach 5 - Total Mercury: Eco-Risk Screening

All species whole fish (composites) exceeded the eco-risk screening value for fish-eating birds in Reach 5. All species whole fish composites, with the exception of one whole white sucker composite, exceeded the eco-risk screening value for fish-eating mammals (Figure 16; Tables 11 and 12).

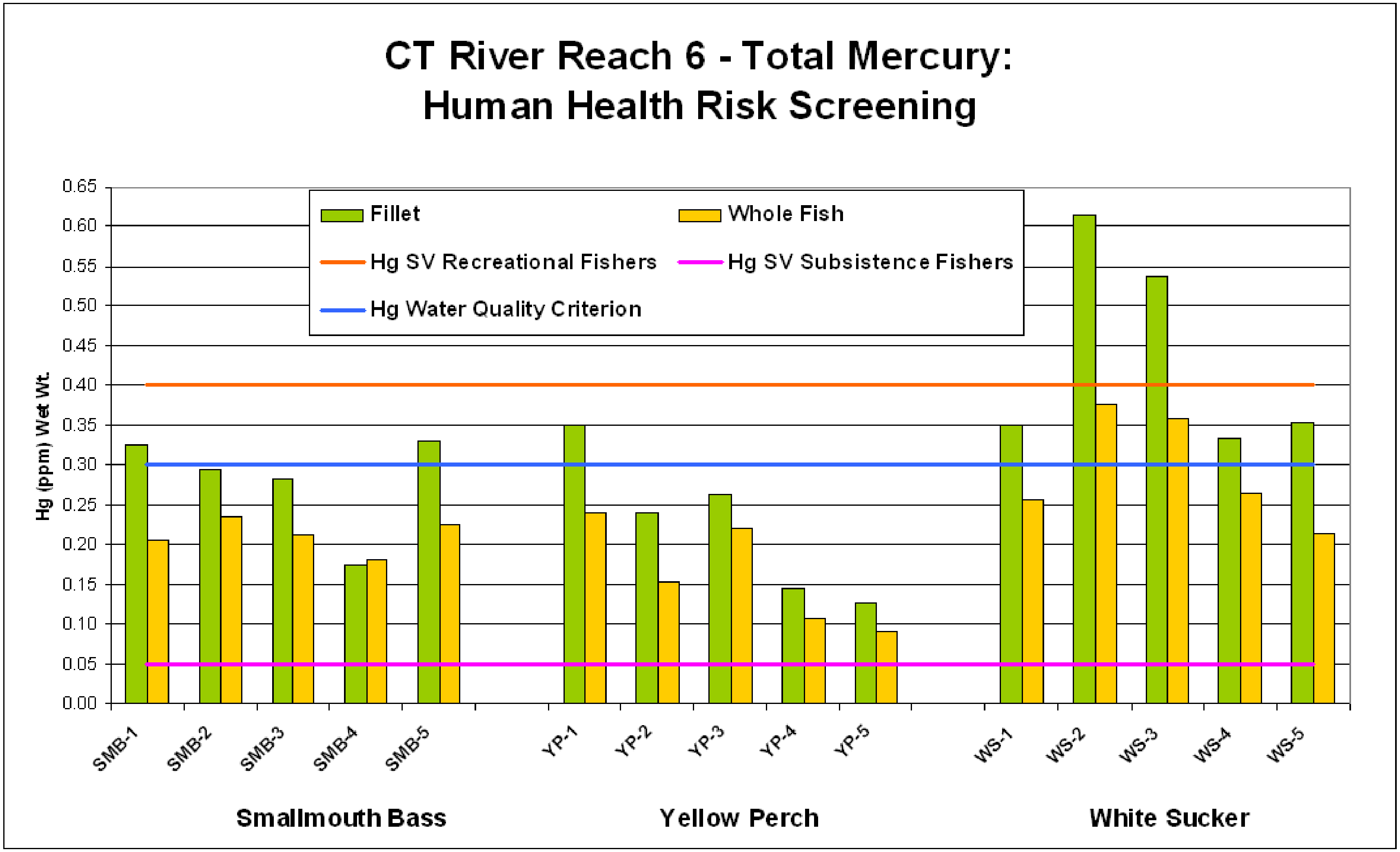

Table 17. CT River Reach 6 - Total Mercury: Human Health Risk Screening

Total mercury in Reach 6 in smallmouth bass and yellow perch was below the SV for recreational fishers. Two white sucker fillets exceeded the SV for recreational fishers. All three species had samples that exceeded the MeHg-WQC. All species and samples, exceeded the SV for subsistence fishers (Figure 17; Tables 11 and 12).

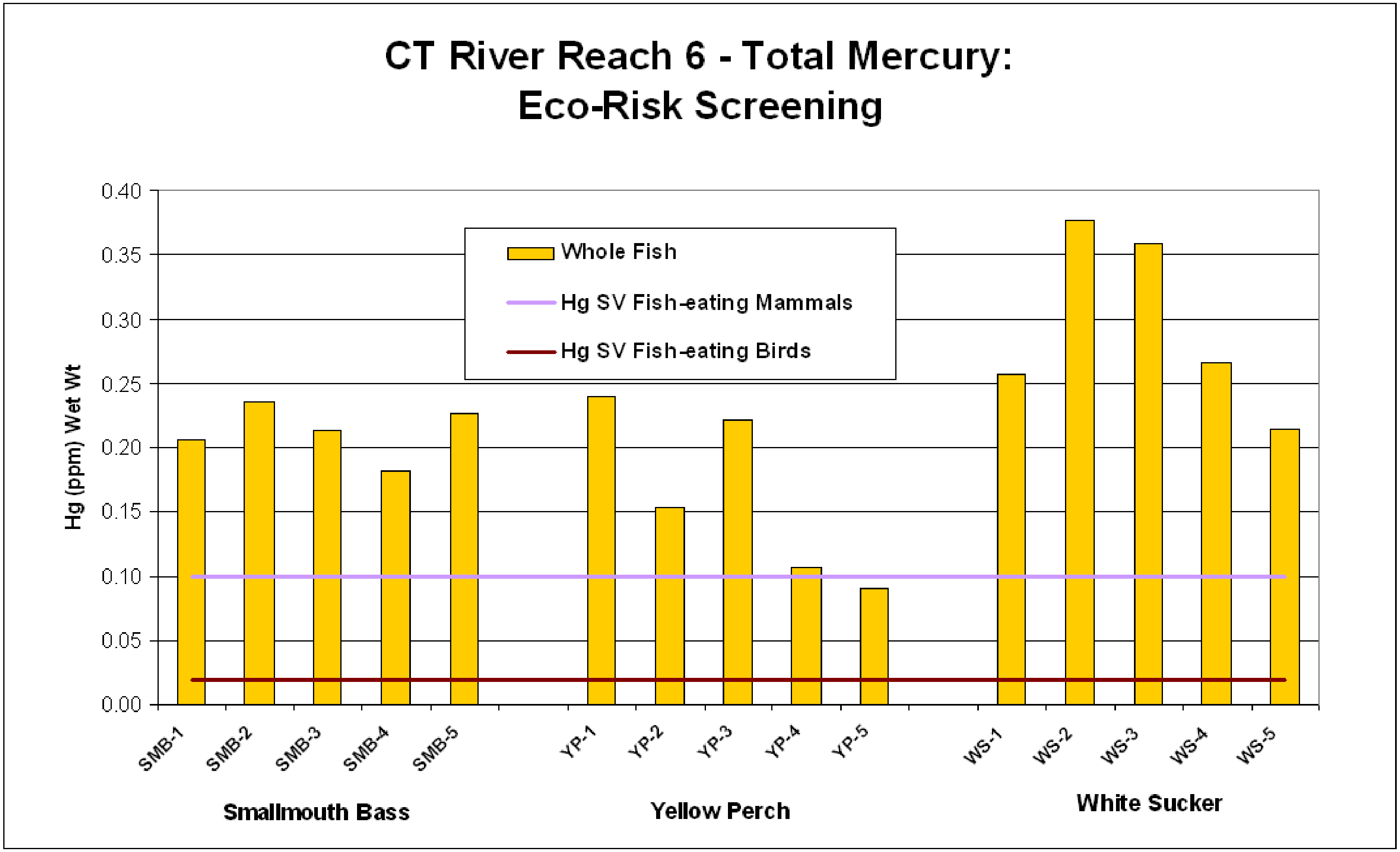

Figure 18. CT River Reach 6 - Total Mercury: Eco-Risk Screening

All species and composites in Reach 6, with the exception of YP-5, exceeded eco-risk screening values for fish-eating birds and mammals (Figure 18; Tables 11 and 12).

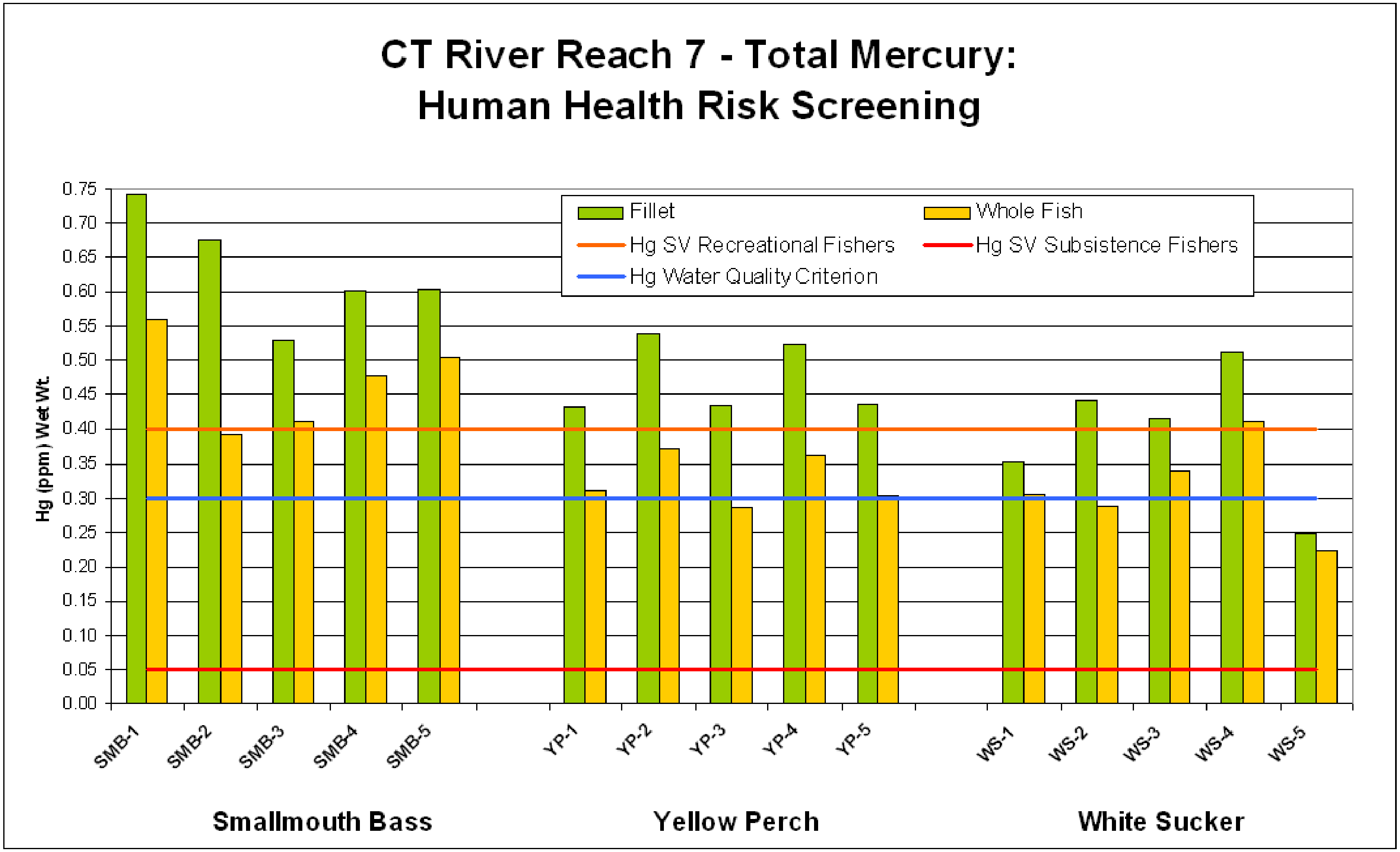

Figure 19. CT River Reach 7 - Total Mercury: Human Health Risk Screening

Total mercury in Reach 7 in all species had samples that exceeded the SV for recreational fishers. All three species exceeded the MeHg-WQC for most of their samples. All species and samples, exceeded the SV for subsistence fishers (Figure 19; Tables 11 and 12).

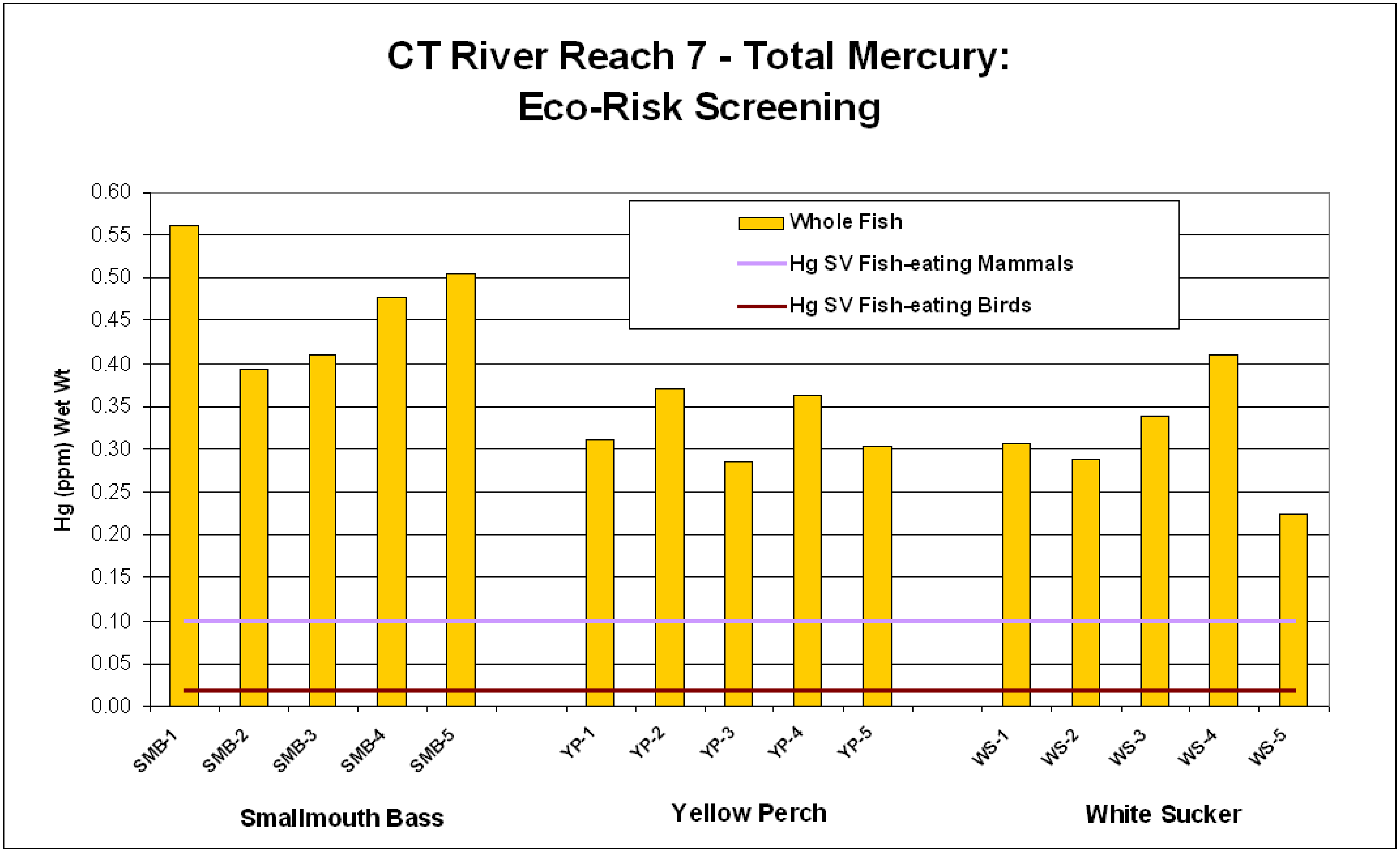

Figure 20. CT River Reach 7 - Total Mercury: Eco-Risk Screening

All species and composites in Reach 7 substantially exceeded eco-risk screening values for both fish-eating birds and mammals (Figure 20; Tables 11 and 12).

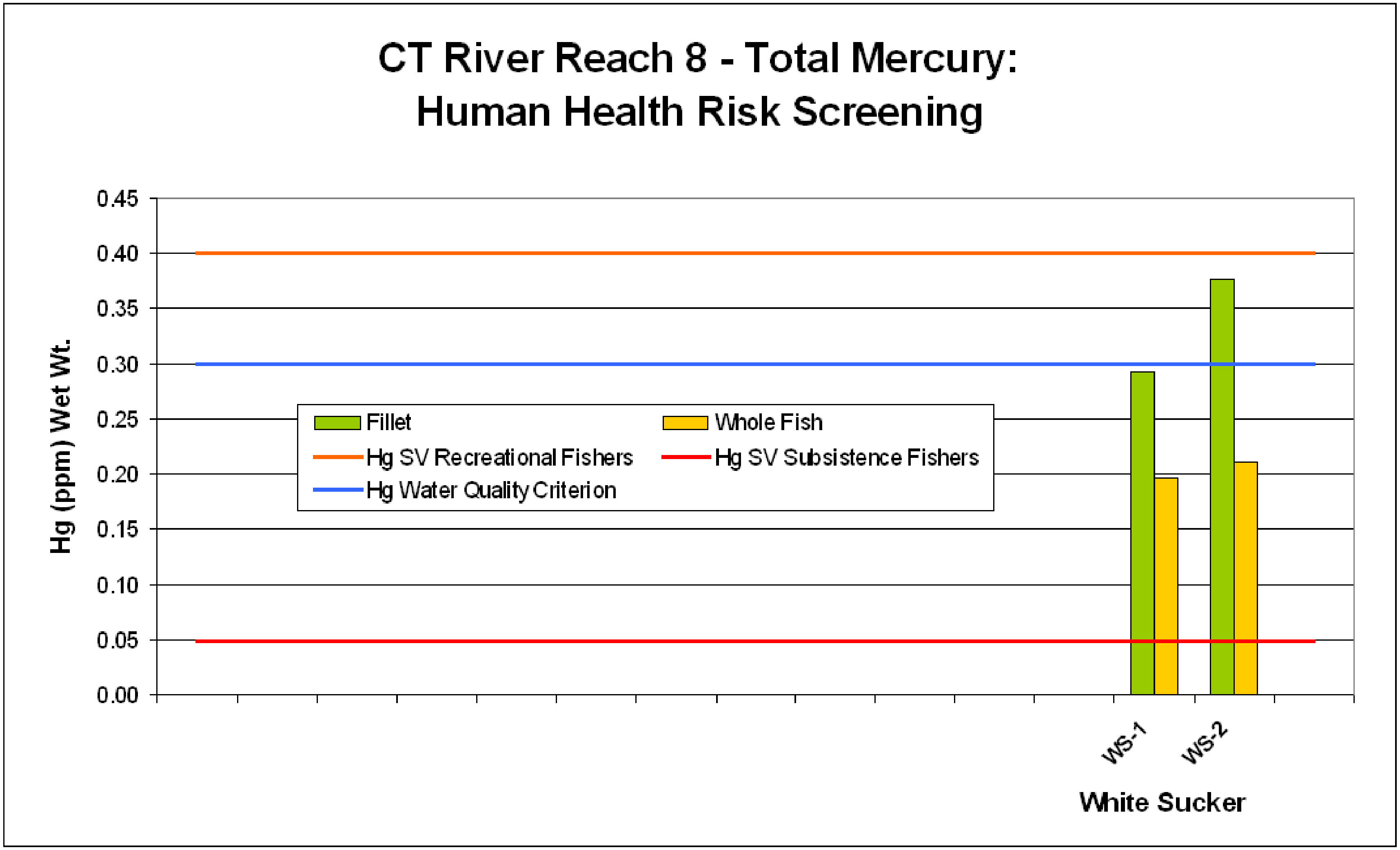

Figure 21. CT River Reach 8 - Total Mercury: Human Health Risk Screening

The two white sucker samples from Reach 8 had total Hg that was below the SV for recreational fishers. However, the fillet in WS-1 approached the MeHg-WQC and in WS-2 exceeded this criterion. Both samples exceeded the SV for subsistence fishers (Figure 21; Tables 11 and 12).

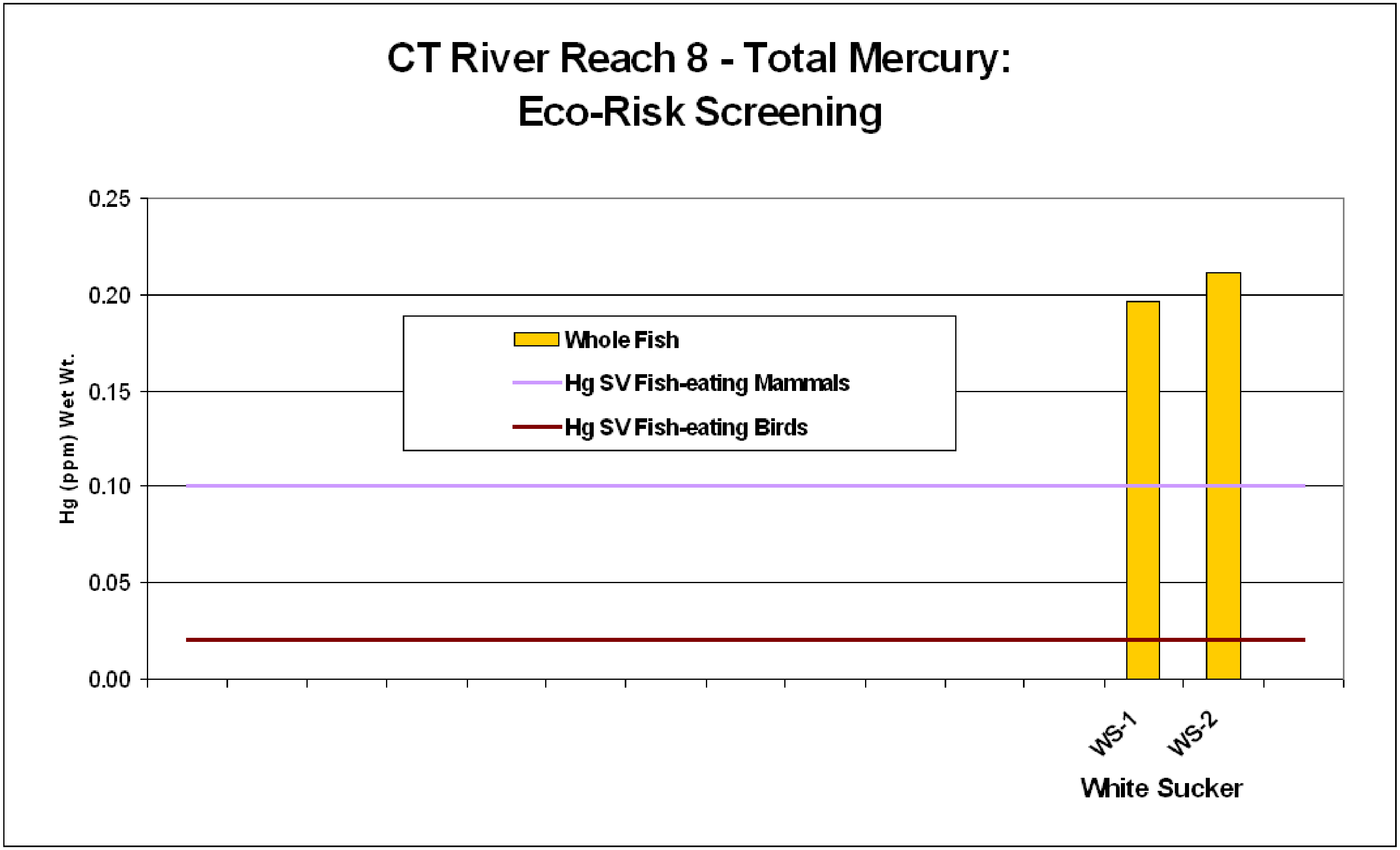

Figure 22. CT River Reach 8 - Total Mercury: Eco-Risk Screening

Both white sucker composites from Reach 8 exceeded eco-risk screening values for fish-eating birds and mammals (Figure 22; Tables 11 and 12).

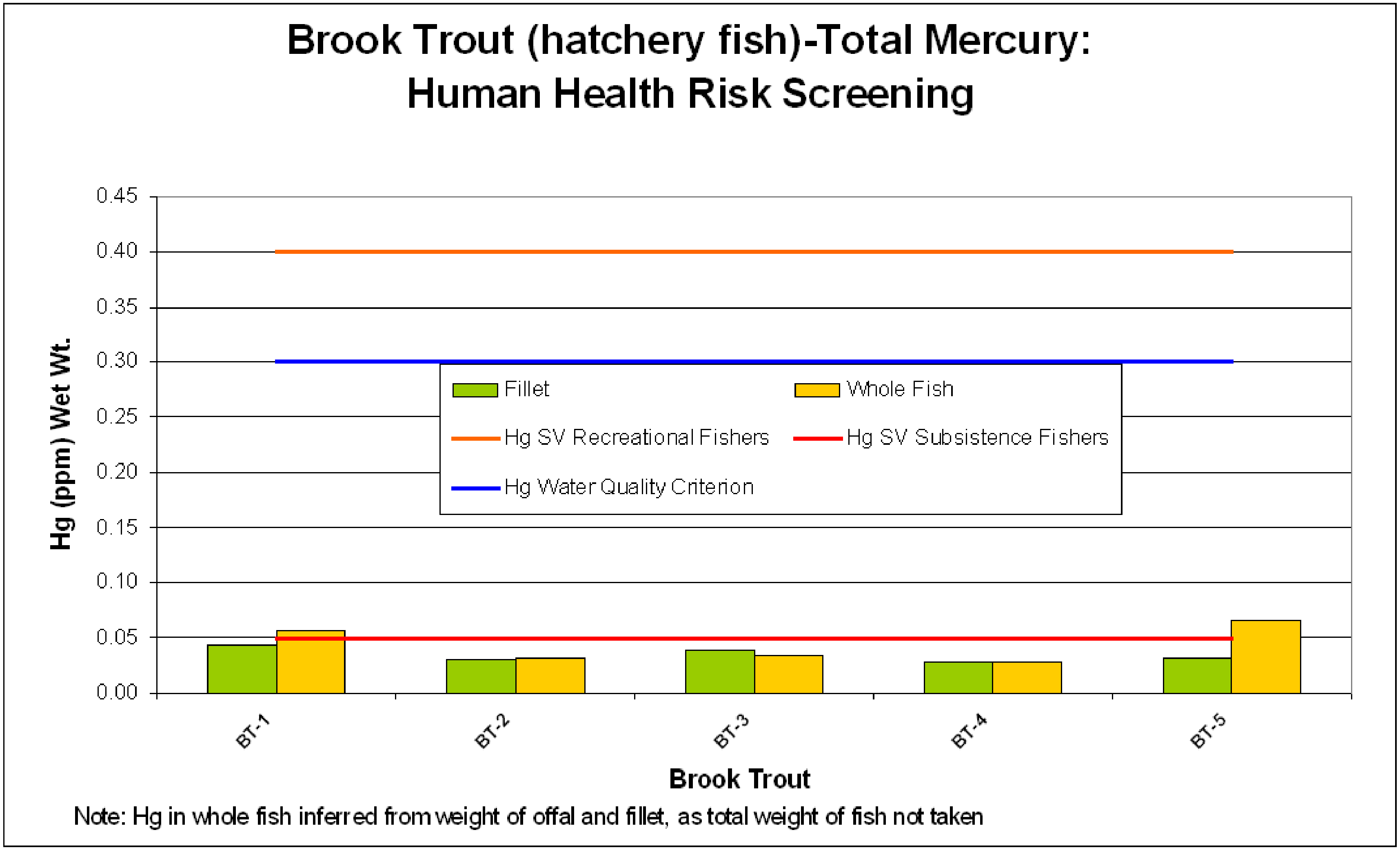

Figure 23. Brook Trout (hatchery fish) - Total Mercury: Human Health Risk Screening

Brook trout did not exceed either the SV for recreational fishers or the MeHG-WQC. Two whole fish samples (BT-1 and BT-5) exceeded the SV for subsistence fishers (Figure 23; Tables 11 and 12).

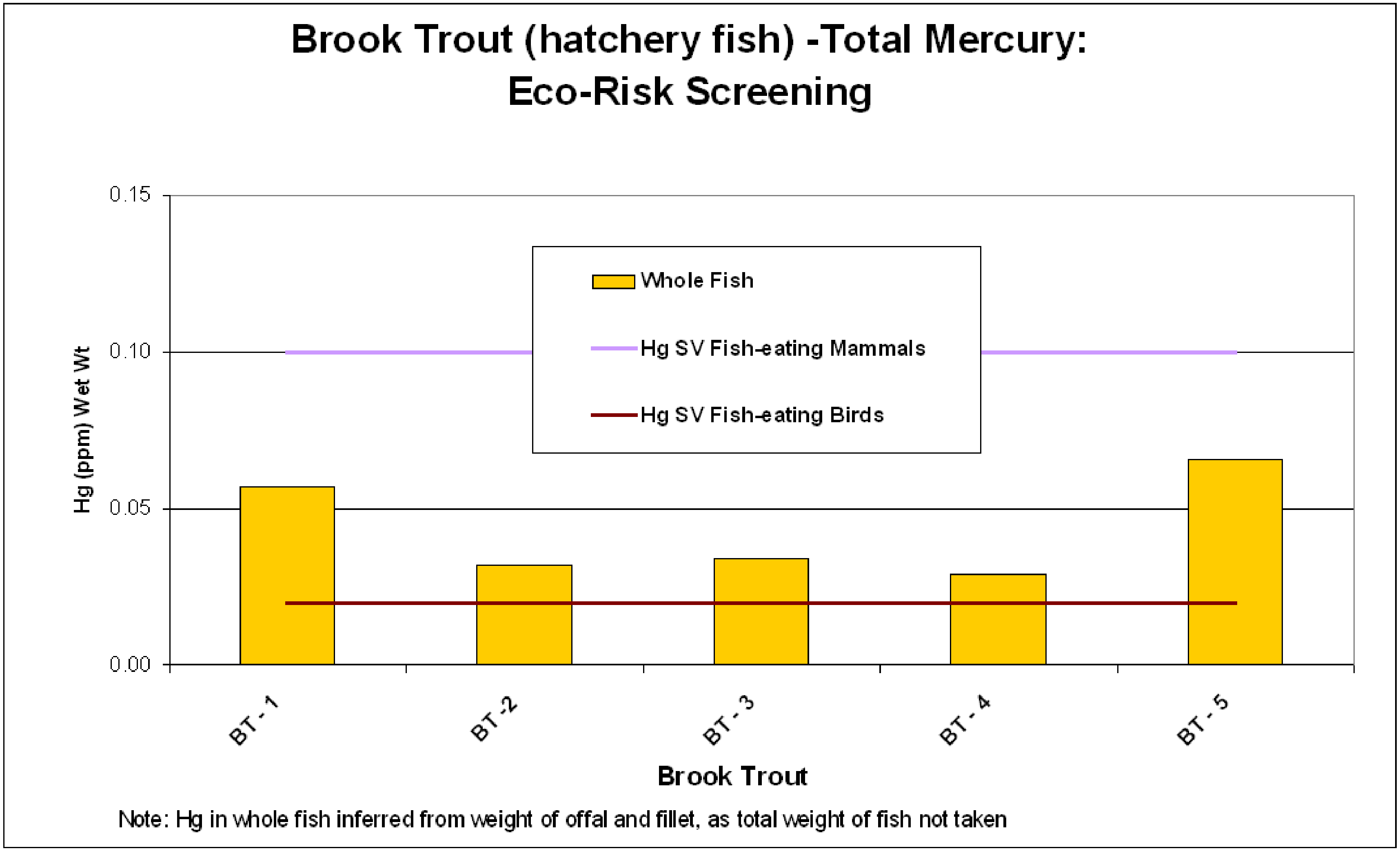

Figure 24. Brook Trout (hatchery fish) - Total Mercury: Eco-Risk Screening

No brook trout composites exceeded the eco-risk SV for fish-eating mammals. All brook trout composites exceeded the eco-risk SV for fish-eating birds (Figure 24; Tables 11 and 12).

Table 11. Total Mercury (ppm - wet weight) in Connecticut River Fish Species (Fillet, Offal, and Whole Fish) Sampled by Reach

Reach 1	Hg-Fillet	Hg-Offal	Hg-Whole Fish
SMB-1	0.17	0.11	0.13
SMB-2	0.21	0.11	0.14
SMB-3	0.19	0.13	0.15
SMB-4	0.17	0.11	0.15
SMB-5	0.20	0.11	0.14
YP-1	0.08	0.07	0.07
YP-2	0.09	0.05	0.07
YP-3	0.10	0.08	0.08
YP-4	0.12	0.05	0.08
YP-5	0.07	--	--
WS-1	0.16	0.05	0.09
WS-2	0.17	0.06	0.10
WS-3	0.10	0.09	0.06
WS-4	0.10	0.05	0.07
WS-5	0.06	0.04	0.04

Reach 2	Hg-Fillet	H g-Offal	Hg-Whole Fish
SMB-1	0.44	0.25	0.30
SMB-2	0.25	0.10	0.15
SMB-3	0.17	0.12	0.13
SMB-4	0.27	0.16	0.20
SMB-5	0.32	0.22	0.24
YP-1	0.11	0.05	0.07
YP-2	0.21	0.12	0.14
YP-3	0.13	0.06	0.08
YP-4	0.12	0.11	0.11
YP-5	0.16	0.12	0.13
WS-1	0.10	0.05	0.06
WS-2	0.10	0.08	0.09
WS-3	0.17	0.07	0.10
WS-4	0.23	0.10	0.16
WS-5	0.08	0.06	0.06

Reach 3	Hg-Fillet	H g-Offal	Hg-Whole Fish
SMB-1	0.28	0.17	0.21
SMB-2	0.33	0.21	0.25
SMB-3	0.61	0.25	0.38
SMB-4	0.41	0.38	0.38
SMB-5	0.19	0.10	0.13
YP-1	0.14	0.07	0.10
YP-2	0.07	0.06	0.06
YP-3	0.09	0.05	0.06
YP-4	0.13	0.04	0.07
YP-5	0.15	0.07	0.10
WS-1	0.10	0.05	0.07
WS-2	--	--	--
WS-3	0.10	0.04	0.22
WS-4	0.11	0.06	0.08
WS-5	0.25	0.12	0.16

BBH-1	N/A	N/A	0.04
BBH-2	N/A	N/A	0.06
BBH-3	N/A	N/A	0.04
BBH-4	N/A	N/A	0.04
BBH-5	N/A	N/A	0.05
AS-1	0.04	0.02	0.03
AS-2	0.04	0.02	0.03
AS-3	0.04	0.03	0.03
AS-4	0.05	0.02	0.03
AS-5	0.03	0.02	0.03
SB-1	0.28	0.17	0.21
SB-2	0.23	0.13	0.17
SB-3	0.31	0.17	0.23
SB-4	0.34	0.20	0.25

Reach 4	Hg-Fillet	Hg-Offal	Hg-Whole Fish
SMB-1	0.20	0.13	0.15
SMB-2	0.29	0.17	0.20
SMB-3	0.38	0.19	0.24
SMB-4	0.44	0.30	0.34
SMB-5	0.33	0.20	0.23
YP-1	0.16	0.08	0.11
YP-2	0.25	0.13	0.17
YP-3	0.14	0.08	0.10
YP-4	0.18	0.11	0.13
YP-5	0.17	0.09	0.11
WS-1	0.09	0.07	0.08
WS-2	0.25	0.19	0.20
WS-3	0.21	0.16	0.16
WS-4	0.28	0.13	0.17
WS-5	--	--	--

Reach 5	Hg-Fillet	Hg-Offal	Hg-Whole Fish
SMB-1	0.24	0.15	0.17
SMB-2	0.27	0.15	0.19
SMB-3	0.24	0.15	0.17
SMB-4	0.24	0.15	0.18
SMB-5	0.21	0.15	0.16
YP-1	0.12	0.07	0.09
YP-2	0.19	0.10	0.13
YP-3	0.13	0.08	0.09
YP-4	0.11	0.06	0.08
YP-5	0.12	0.07	0.09
WS-1	0.26	0.12	0.17
WS-2	0.25	0.11	0.16
WS-3	0.30	0.14	0.18
WS-4	0.19	0.12	0.14
WS-5	0.17	0.09	0.12

Reach 6	Hg-Fillet	Hg-Offal	Hg-Whole Fish
SMB-1	0.33	0.15	0.21
SMB-2	0.30	0.22	0.24
SMB-3	0.28	0.19	0.21
SMB-4	0.17	0.20	0.18
SMB-5	0.33	0.19	0.23
YP-1	0.35	0.20	0.24
YP-2	0.24	0.11	0.15
YP-3	0.26	0.19	0.22
YP-4	0.15	0.10	0.11
YP-5	0.13	0.08	0.09
WS-1	0.35	0.21	0.26
WS-2	0.62	0.27	0.38
WS-3	0.54	0.27	0.36
WS-4	0.33	0.23	0.27
WS-5	0.35	0.18	0.21

Reach 7	Hg-Fillet	Hg-Offal	Hg-Whole Fish
SMB-1	0.74	0.50	0.56
SMB-2	0.68	0.25	0.39
SMB-3	0.53	0.37	0.41
SMB-4	0.60	0.43	0.48
SMB-5	0.60	0.47	0.51
YP-1	0.43	0.24	0.31
YP-2	0.54	0.28	0.37
YP-3	0.44	0.21	0.29
YP-4	0.53	0.26	0.36
YP-5	0.44	0.22	0.30
WS-1	0.35	0.31	0.31
WS-2	0.44	0.26	0.29
WS-3	0.41	0.32	0.34
WS-4	0.51	0.38	0.41
WS-5	0.25	0.23	0.22

Reach 8	Hg-Fillet	Hg-Offal	Hg-Whole Fish
WS-1	0.29	0.14	0.20
WS-2	0.38	0.13	0.21

Brook Trout	Hg-Fillet	Hg-Offal	Hg-Whole Fish
BT - 1	0.04	0.08	0.06
BT -2	0.03	0.03	0.03
BT - 3	0.04	0.03	0.03
BT - 4	0.03	0.03	0.03
BT - 5	0.03	0.12	0.07

Missing Data Codes:
-- No data available for QA/QC Reasons (see Appendix D-1)
N/A Not Applicable, e.g. only whole fish analyzed
Species Codes:
SMB - Smallmouth Bass; YP - Yellow Perch; WS - White Sucker;
BBH - Brown Bullhead; AS - American Shad; SB - Striped Bass;
BT - Brook Trout (hatchery controls)

2.10 Summary of Total Mercury Human Health and Eco-Risk Screening

Table 12. Number of Composites by Species and Reach exceeding EPA Mercury Human Health and Eco-Risk Screening Values (n = total # of composites or individual fish, in the case of American shad and Striped bass) (F-fillet, W-Whole Fish)

Reach	Species	EPA Human Health Risk Screening Values						EPA Eco-Risk Screening Values	
		Recreational Fishers (0.4 ppm)		Subsistence Fishers (0.049 ppm)		Water Quality Criterion (0.3 ppm)		Fish-eating Mammals (0.1 ppm)	Fish-eating Birds (0.02 ppm)
		F	W	F	W	F	W	Whole	Whole
1 (n=5)	Smallmouth Bass	0	0	5	5	0	0	5	5
	Yellow Perch (n=4 for Whole Fish)	0	0	5	4	0	0	0	5
	White Suckers	0	0	5	4	0	0	1	5
2 (n=5)	Smallmouth Bass	1	0	5	5	2	1	5	5
	Yellow Perch	0	0	5	5	0	0	3	5
	White Suckers	0	0	5	5	0	0	2	5
3	Smallmouth Bass (n=5)	2	0	5	5	3	0	5	5
	Yellow Perch (n=5)	0	0	5	5	0	0	2	5
	White Suckers (n=4)	0	0	4	4	0	0	2	4
	Brown Bullhead (n=5)	N/A	0	N/A	2	N/A	0	0	5
	American Shad (n=5)	0	0	1	0	0	0	0	5
	Striped Bass (n=4)	0	0	4	4	2	0	4	4

Reach	Species	EPA Human Health Risk Screening Values						EPA Eco-Risk Screening Values	
		Recreational Fishers (0.4 ppm)		Subsistence Fishers (0.049 ppm)		Water Quality Criterion (0.3 ppm)		Fish-eating Mammals (0.1 ppm)	Fish-eating Birds (0.02 ppm)
		F	W	F	W	F	W	Whole	Whole
4	Smallmouth Bass (n=5)	1	0	5	5	3	1	5	5
	Yellow Perch (n=5)	0	0	5	5	0	0	5	5
	White Suckers (n=4)	0	0	4	4	0	0	3	4
5 (n=5)	Smallmouth Bass	0	0	5	5	0	0	5	5
	Yellow Perch	0	0	5	5	0	0	1	5
	White Suckers	0	0	5	5	1	0	5	5
6 (n=5)	Smallmouth Bass	0	0	5	5	3	0	5	5
	Yellow Perch	0	0	5	5	1	0	4	5
	White Suckers	2	0	5	5	5	2	5	5
7 (n=5)	Smallmouth Bass	5	4	5	5	5	5	5	5
	Yellow Perch	5	0	5	5	5	4	5	5
	White Suckers	3	1	5	5	4	3	5	5

Reach	Species	EPA Human Health Risk Screening Values						EPA Eco-Risk Screening Values	
		Recreational Fishers (0.4 ppm)		Subsistence Fishers (0.049 ppm)		Water Quality Criterion (0.3 ppm)		Fish-eating Mammals (0.1 ppm)	Fish-eating Birds (0.02 ppm)
		F	W	F	W	F	W	Whole	Whole
8 (n=2)	White Suckers	0	0	2	2	1	0	2	2
BT (n=5)	Brook trout	0	0	0	2	0	0	0	5

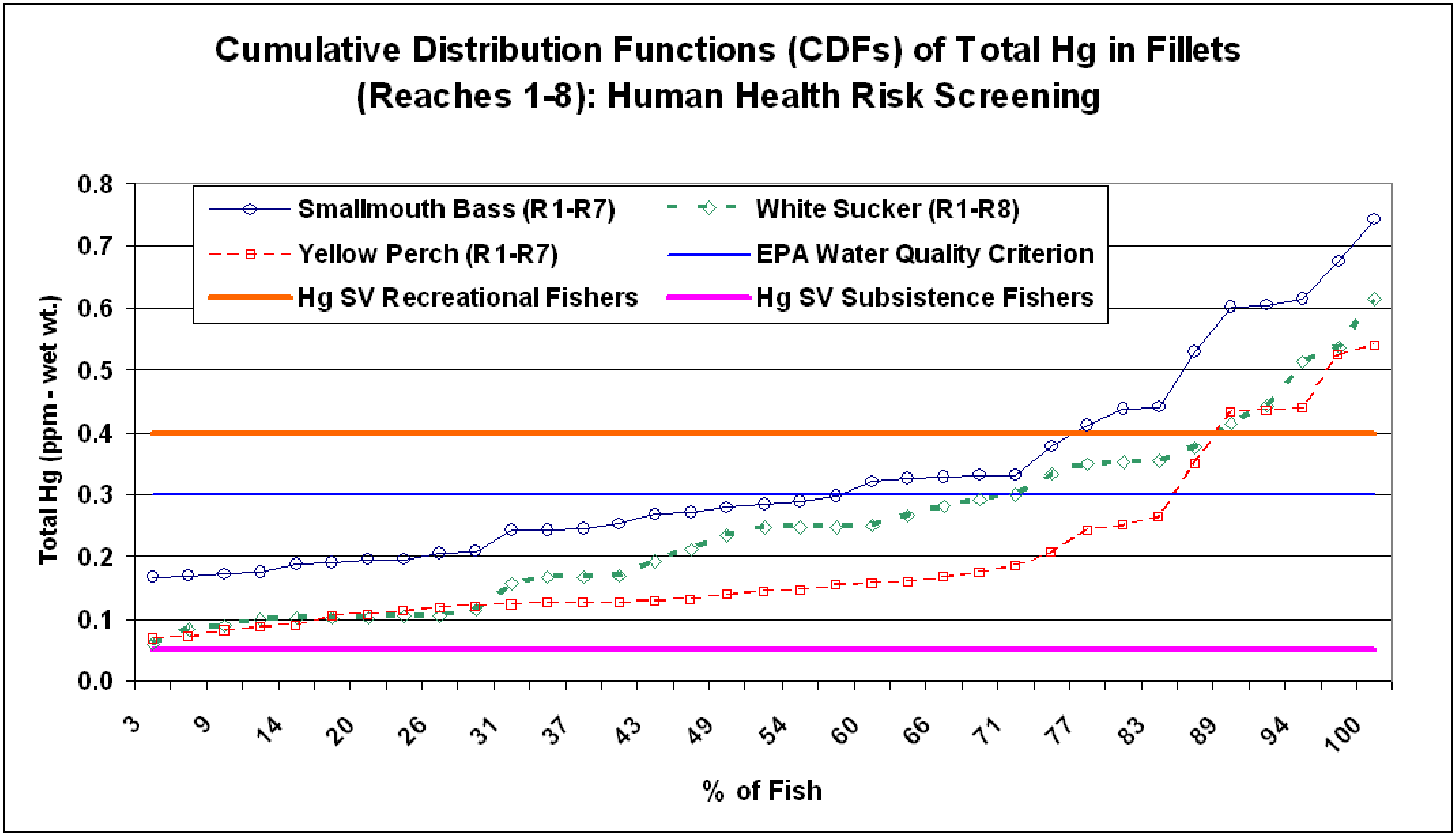

Figure 25. Cumulative Distribution Functions (CDFs) of Total Mercury in Fillets (Reaches 1-8): Human Health Risk Screening

All SMB, YP, and WS fillets exceeded the EPA Hg subsistence fisher screening value (Figure 25; Table 13). 46% of SMB, 17% of YP, and 31% of WS fillets exceeded the EPA Hg Water Quality Criterion. 26% of SMB, 13% of YP, and 14% of WS fillets exceeded the EPA Hg recreational fisher screening value.

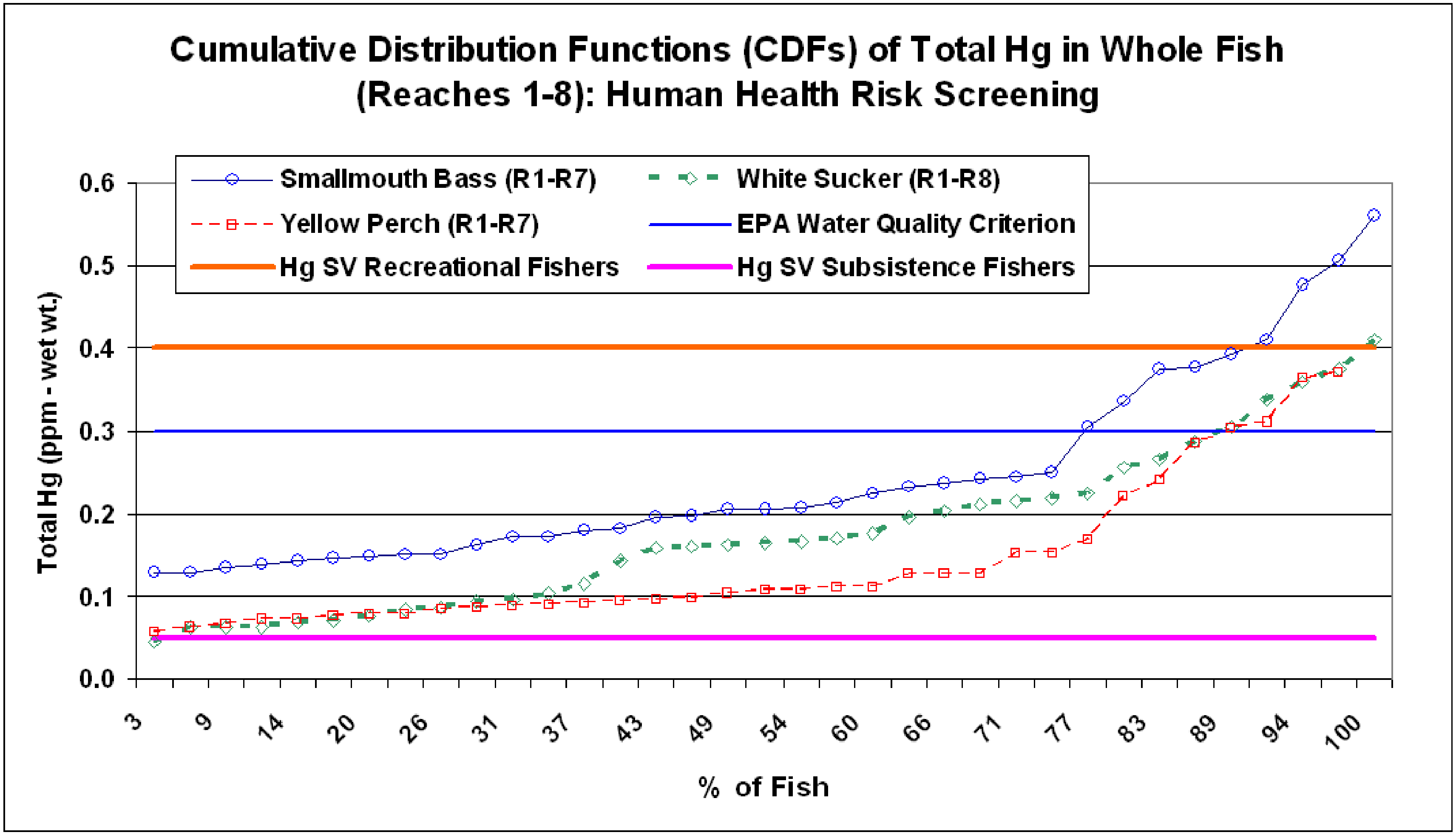

Figure 26. Cumulative Distribution Functions (CDFs) of Total Hg in Whole Fish (Reaches 1-8): Human Health Risk Screening

All whole SMB, whole YP, and 97% of whole WS exceeded the EPA Hg subsistence fisher screening value (Figure 26; Table 13). 26% of whole SMB, 12% of whole YP, and 14% of whole WS exceeded the EPA Water Quality Criterion. 11% of whole SMB, no whole YP, and only 3% of whole WS exceeded the EPA Hg recreational fisher screening value.

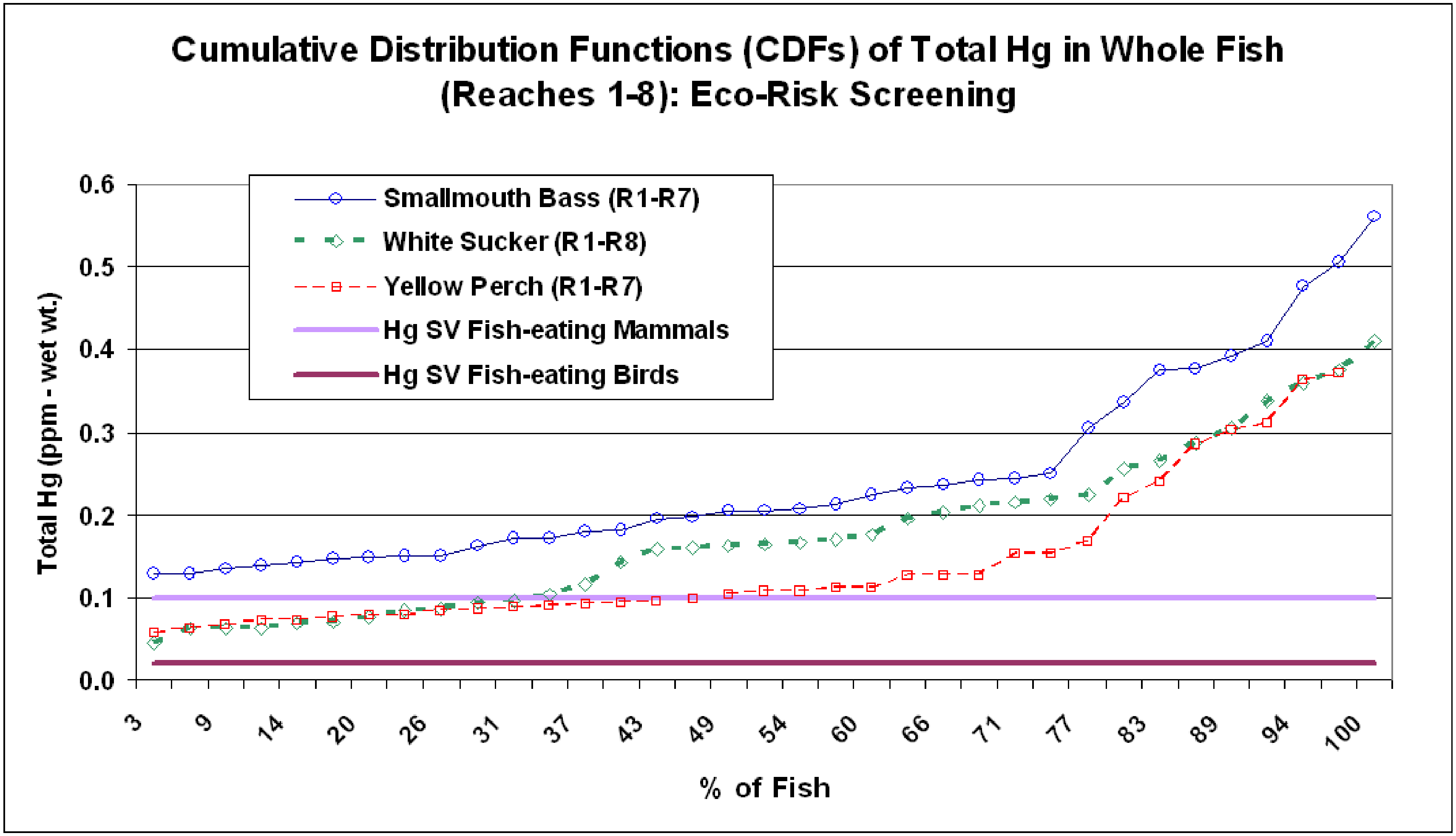

Figure 27. Cumulative Distribution Functions (CDFs) of Total Mercury in Whole Fish (Reaches 1-8): Eco-Risk Screening

All whole smallmouth bass, yellow perch and white suckers exceeded the eco-risk screening value for fish-eating birds (Figure 27; Table 13). All whole smallmouth bass, 39% of whole yellow perch, and 71% of whole white suckers exceeded the eco-risk screening value for fish-eating mammals.

Table 13. Percentage of Fillet and Whole Fish Samples from all Reaches above Mercury Human Health and Eco-Risk Screening Criteria

Species	Fillet or Whole Fish	% > Subsistence Fisher SV (0.049 ppm)	% > EPA Water Quality Criterion (0.3 ppm)	% > Recreational Fisher SV (0.4 ppm)	% > Bird SV (0.02 ppm)	% > Mammal SV (0.1 ppm)
Smallmouth Bass	Fillets	100%	46%	26%		
	Whole	100%	26%	11%	100%	100%
Yellow Perch	Fillets	100%	17%	13%		
	Whole	100%	12%	0%	100%	39%
White Sucker	Fillets	100%	31%	14%		
	Whole	97%	14%	3%	100%	71%

In Reach 1 all three species for both fillets and whole fish did not exceed EPA's recreational fisher SV. However, all exceeded EPA's SV for subsistence fishers. EPA's Water Quality Criterion was not exceeded by any species.

All three species in Reach 1 exceeded the eco-risk SV for fish-eating birds. Similarly all smallmouth bass exceeded the eco-risk SV for fish-eating mammals. However, no yellow perch exceeded the mammalian eco-risk SV and only a single white sucker exceeded it.

In Reach 2 only a single smallmouth bass fillet exceeded EPA's recreational fisher SV. However, all samples exceeded EPA's subsistence fisher SV. Only two smallmouth bass fillets and single whole smallmouth bass exceeded EPA's water quality criterion.

All three species in Reach 2 exceeded the bird SV. All smallmouth bass, three yellow perch and two white suckers exceeded the mammalian SV.

In Reach 3 only two smallmouth bass fillets exceeded EPA's recreational fisher SV. However, all smallmouth bass, yellow perch and white sucker fillets and whole fish exceeded EPA's subsistence fisher SV. Two whole brown bullheads exceeded this value. Only a single shad fillet exceeded this value. All striped bass fillets and whole fish exceeded EPA's subsistence fisher SV. Three smallmouth bass fillets and two striped bass fillets exceeded EPA's water quality criterion. No whole fish in Reach 5 exceeded this value.

All samples from all species in Reach 3 exceeded the bird SV. Similarly, all smallmouth bass and striped bass exceeded the mammalian SV. Only two yellow perch and white suckers and no brown bulleads or American shad exceeded this value.

Only a single smallmouth bass fillet in Reach 4 exceeded EPA's recreational fisher SV. However, all fillets and whole fish in all species exceeded EPA's subsistence fisher SV. Only 3 smallmouth bass fillets and a single whole fish exceeded EPA's water quality criterion.

All samples for all species in Reach 4 exceeded the bird SV. All but one white sucker exceeded the mammalian SV.

In Reach 5 no fillets or whole fish in any species exceeded EPA's recreational SV. However, all fillets and whole fish in all species exceeded EPA's subsistence SV. Only a single white sucker fillet exceeded EPA's water quality criterion.

All whole fish of all species exceeded the bird SV in Reach 5. Also all smallmouth bass, all white suckers, and only one yellow perch exceeded the mammalian SV.

In Reach 6 only two white sucker fillets exceeded EPA's recreational fisher SV. However, all fillets and whole fish in all species exceeded EPA's subsistence fisher SV. Three smallmouth bass fillets, one yellow perch fillet, and all five white sucker fillets exceeded EPA's water quality criterion. Only two whole white suckers exceeded EPA's water quality criterion

In Reach 6 all whole fish in all species exceeded the bird SV and all but one yellow perch exceeded the mammalian SV.

In Reach 7 all smallmouth bass and yellow perch fillets and three white sucker fillets exceeded EPA's recreational fisher SV. All fillets and whole fish in all species exceeded EPA's subsistence fisher SV. All smallmouth bass fillets and whole fish exceeded EPA's water quality criterion. All five yellow perch fillets and four whole fish exceeded this value. Four white sucker fillets and three whole white suckers exceeded this value.

In Reach 7 all whole fish in all species exceeded both bird and mammalian SVs.

Neither white sucker fillet from Reach 8 exceeded EPA's recreational fisher SV. However, both exceeded EPA's subsistence fisher SV. Only one fillet and no whole fish exceeded EPA's water quality criterion.

Both whole white suckers from Reach 8 exceeded the bird and mammalian SV.

The risk to recreational fishers does not appear to increase until Reach 7. Clearly subsistence fishers are at much greater risk than recreational fishers, from fillets or whole fish, from all Reaches. EPA's water quality criterion is exceeded more for smallmouth bass fillets in both Reach 3 and 4, than Reaches 1, 2, or 5. Reaches 6 and 7 also exceed this criterion more than other Reaches.

Fish-eating birds are at risk from smallmouth bass, yellow perch and white suckers from all Reaches. Mammals are also at risk, however, this risk appears to increase from Reaches 4 through 8.

Only two of the whole brook trout (control fish) raised in a Connecticut fish hatchery exceeded EPA's subsistence fisher SV, and none exceeded EPA's recreational fisher SV. These brook trout also only posed an eco-risk to fish-eating birds, not mammals.

2.11 Correlation of Total Mercury in Fillets and Whole Fish

A highly statistically significant positive correlation was observed between total mercury in whole smallmouth bass and fillets (Figure 28). Highly similar correlations were found for yellow perch and white suckers between total mercury in fillets and whole fish.

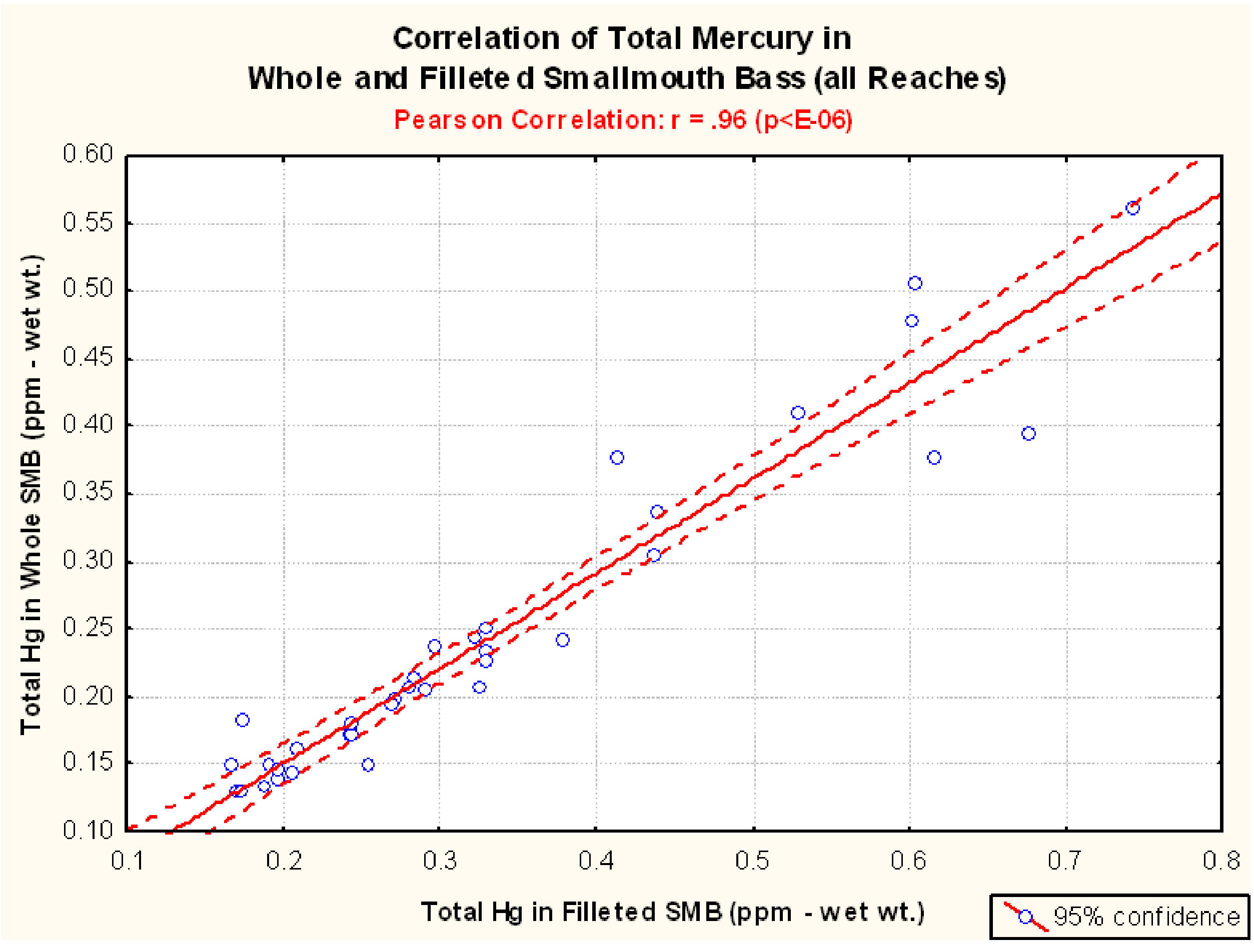

Figure 28. Correlation of Total Mercury in Whole and Filleted Smallmouth Bass (all Reaches)

2.12 Total Mercury - Analysis of Variance (ANOVA) by Species and Reach
A parametric statistical analysis of variance (ANOVA) was performed on the mercury data comparing species and Reaches to explore patterns in the data.

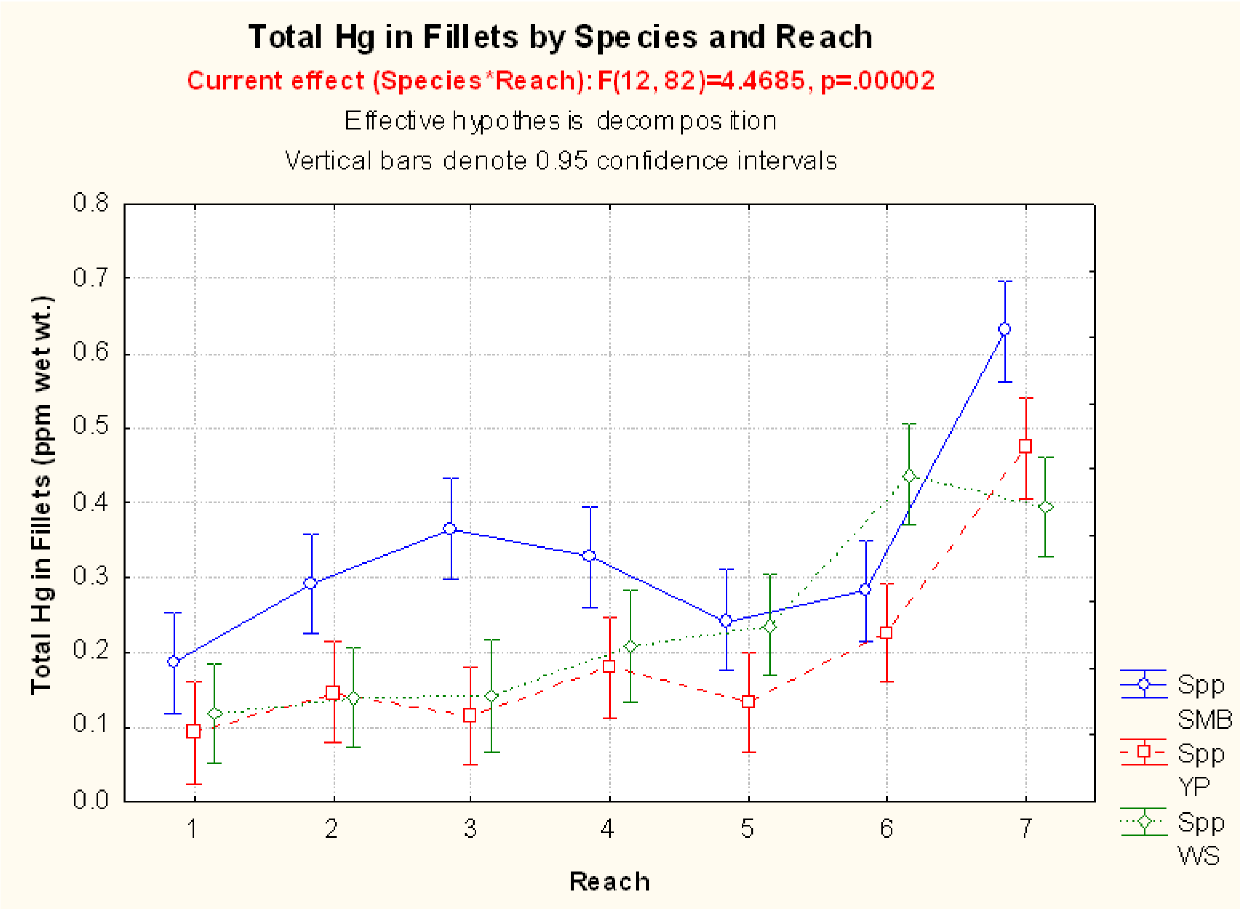

Figure 29. Factorial ANOVA of Total Mercury in Fillets by Species and Reach

A factorial ANOVA was performed on total mercury (total Hg) in fillets by species and Reach (Figure 29). A highly significant effect of Reach by Species was observed (p=0.00002). Table 14 summarizes the pair-wise comparison of total Hg in fillets by species and Reach using Fisher's LSD Test. Fisher's "post hoc test (or multiple comparison test) can be used to determine the significant differences between group means in an analysis of variance setting. The Fisher LSD test is considered to be one of the least conservative post hoc tests" (StatSoft 2005).

Table 14. Statistical Comparison of Total Hg in Fillets by Species and Reach (Fisher's LSD Post-Hoc Test of Least Square Means).[33]

Least Square Means		0.19	0.09	0.12	0.29	0.15	0.14	0.36	0.11	0.14	0.33	0.18	0.21	0.24	0.13	0.24	0.28	0.23	0.44	0.63	0.47	0.39
	Spp	SMB	YP	WS	SMB	YP	WS	SMB	YP	WS	SMB	YP	WS	SMB	YP	WS	SMB	YP	WS	SMB	YP	WS
Reach		1	1	1	2	2	2	3	3	3	4	4	4	5	5	5	6	6	6	7	7	7
1	SMB		0.05	0.16	0.03	0.40	0.32	3.37E-04	0.14	0.38	4.16E-03	0.89	0.67	0.25	0.27	0.31	0.05	0.41	1.08E-06	1.77E-14	4.58E-08	3.79E-05
1	YP			0.60	7.69E-05	0.27	0.34	1.85E-07	0.65	0.34	4.69E-06	0.07	0.03	2.49E-03	0.40	3.72E-03	1.61E-04	0.01	2.33E-10	0.00E+00	7.61E-12	1.33E-08
1	WS				4.73E-04	0.55	0.67	1.59E-06	0.95	0.64	3.46E-05	0.20	0.08	0.01	0.75	0.02	9.34E-04	0.03	2.39E-09	0.00E+00	8.14E-11	1.25E-07
2	SMB					3.10E-03	1.90E-03	0.13	3.85E-04	4.04E-03	0.46	0.02	0.10	0.30	1.32E-03	0.24	0.84	0.17	2.97E-03	4.12E-10	2.61E-04	3.46E-02
2	YP						0.87	1.63E-05	0.51	0.93	2.89E-04	0.49	0.23	0.05	0.78	0.06	0.01	0.10	3.20E-08	3.33E-16	1.17E-09	1.46E-06
2	WS							8.76E-06	0.62	0.95	1.65E-04	0.39	0.18	0.03	0.91	0.05	3.55E-03	0.07	1.59E-08	2.22E-16	5.67E-10	7.53E-07
3	SMB								1.24E-06	3.18E-05	0.43	2.07E-04	2.61E-03	0.01	5.59E-06	0.01	0.09	4.63E-03	0.13	3.21E-07	0.02	0.54
3	YP									0.60	2.76E-05	0.18	0.07	0.01	0.71	0.01	7.67E-04	0.02	1.83E-09	0.00E+00	6.18E-11	9.65E-08
3	WS										4.51E-04	0.46	0.22	0.05	0.86	0.07	0.01	0.10	9.89E-08	3.66E-15	4.55E-09	3.41E-06
4	SMB											2.73E-03	0.02	0.08	1.10E-04	0.06	0.35	0.04	0.02	1.09E-08	2.83E-03	0.16
4	YP												0.58	0.19	0.33	0.24	0.04	0.33	6.03E-07	9.21E-15	2.48E-08	2.23E-05
4	WS													0.50	0.14	0.58	0.15	0.72	1.87E-05	1.40E-12	1.13E-06	4.10E-04
5	SMB														0.03	0.89	0.41	0.74	9.49E-05	3.66E-12	5.55E-06	2.01E-03
5	YP															0.03	2.51E-03	0.05	9.61E-09	1.11E-16	3.38E-10	4.69E-07
5	WS																0.34	0.84	5.85E-05	1.98E-12	3.27E-06	1.32E-03
6	SMB																	0.25	1.58E-03	1.62E-10	1.26E-04	0.02
6	YP																		2.78E-05	7.92E-13	1.46E-06	6.93E-04
6	WS																			1.21E-04	0.45	0.36
7	SMB																				1.52E-03	3.90E-06
7	YP																					0.10

[33]Probability values in red in all tables in this report are statistically significant at 0.05 or lower.

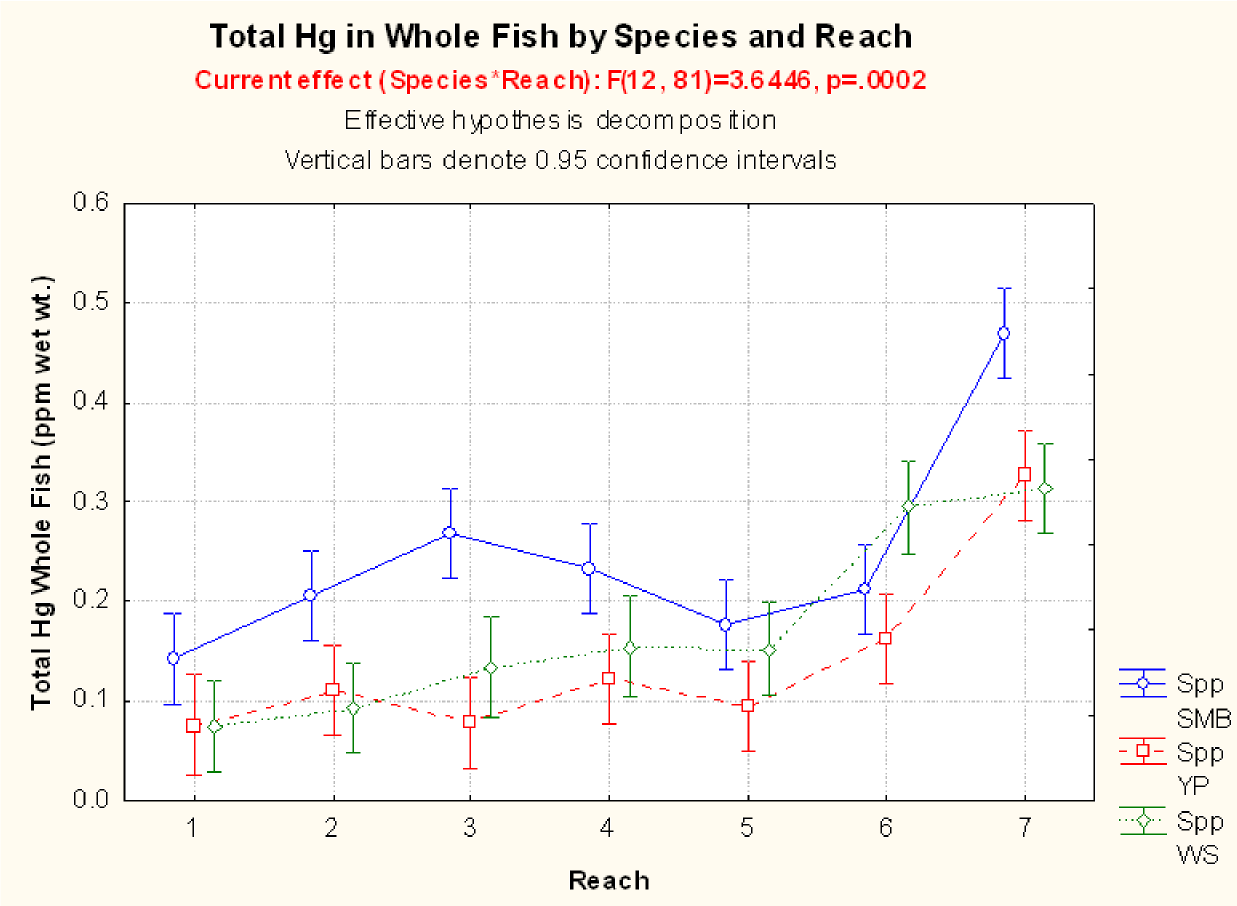

Figure 30. ANOVA of Total Mercury in Whole Fish by Species and Reach

A factorial ANOVA was performed on total Hg in whole fish by species and Reach (Figure 30). A significant effect of Reach*Species was observed (p=0.0002). Table 15 summarizes the pair-wise comparison of total Hg in whole fish by species and Reach.

Table 15. Statistical Comparison of Total Hg in Whole Fish by Species and Reach (Fisher's LSD Post-Hoc Test of LS Means).

Least Square Means		0.14	0.07	0.07	0.20	0.11	0.09	0.27	0.08	0.13	0.23	0.12	0.15	0.18	0.09	0.15	0.21	0.16	0.29	0.47	0.33	0.31
	Spp.	SMB	YP	WS	SMB	YP	WS	SMB	YP	WS	SMB	YP	WS	SMB	YP	WS	SMB	YP	WS	SMB	YP	WS
Reach		1	1	1	2	2	2	3	3	3	4	4	4	5	5	5	6	6	6	7	7	7
1	SMB		0.05	0.04	0.06	0.33	0.13	1.93E-04	0.05	0.81	0.01	0.54	0.74	0.30	0.15	0.76	0.03	0.53	1.03E-05	4.44E-16	1.82E-07	1.02E-06
1	YP			0.99	2.93E-04	0.30	0.59	2.34E-07	0.93	0.11	1.61E-05	0.17	0.03	4.07E-03	0.56	0.03	1.32E-04	0.01	9.40E-09	0.00E+00	1.44E-10	8.40E-10
1	WS				1.26E-04	0.26	0.56	5.23E-08	0.91	0.09	5.25E-06	0.14	0.02	2.29E-03	0.53	0.02	5.25E-05	0.01	1.62E-09	0.00E+00	1.83E-11	1.21E-10
2	SMB					4.75E-03	9.02E-04	0.05	1.87E-04	0.04	0.40	0.01	0.14	0.38	1.07E-03	0.11	0.81	0.20	0.01	3.21E-12	3.03E-04	1.20E-03
2	YP						0.59	5.27E-06	0.31	0.51	3.26E-04	0.72	0.21	0.05	0.62	0.20	2.31E-03	0.11	2.06E-07	0.00E+00	2.78E-09	1.73E-08
2	WS							5.96E-07	0.64	0.24	4.78E-05	0.37	0.08	0.01	0.96	0.07	4.05E-04	0.03	2.05E-08	0.00E+00	2.50E-10	1.61E-09
3	SMB								8.43E-08	1.78E-04	0.26	2.13E-05	1.23E-03	0.01	7.38E-07	5.53E-04	0.09	1.55E-03	0.43	2.13E-08	0.08	0.17
3	YP									0.11	8.14E-06	0.17	0.03	3.22E-03	0.60	0.02	7.90E-05	0.01	2.66E-09	0.00E+00	3.03E-11	2.00E-10
3	WS										0.01	0.74	0.58	0.22	0.26	0.59	0.02	0.40	1.12E-05	2.22E-15	2.53E-07	1.28E-06
4	SMB											1.08E-03	0.02	0.09	5.78E-05	0.02	0.55	0.03	0.06	1.50E-10	4.46E-03	0.01
4	YP												0.37	0.10	0.40	0.36	0.01	0.22	9.24E-07	0.00E+00	1.36E-08	8.20E-08
4	WS													0.51	0.09	0.97	0.09	0.80	9.66E-05	3.11E-14	2.70E-06	1.26E-05
5	SMB														0.01	0.46	0.27	0.67	4.59E-04	5.88E-14	1.25E-05	5.98E-05
5	YP															0.08	4.82E-04	0.04	2.57E-08	0.00E+00	3.16E-10	2.03E-09
5	WS																0.07	0.75	3.32E-05	2.00E-15	6.56E-07	3.54E-06
6	SMB																	0.13	0.01	9.68E-12	6.82E-04	2.55E-03
6	YP																		1.06E-04	8.55E-15	2.39E-06	1.23E-05
6	WS																			6.16E-07	0.32	0.56
7	SMB																				3.13E-05	6.35E-06
7	YP																					0.68

2.12.1 Smallmouth Bass

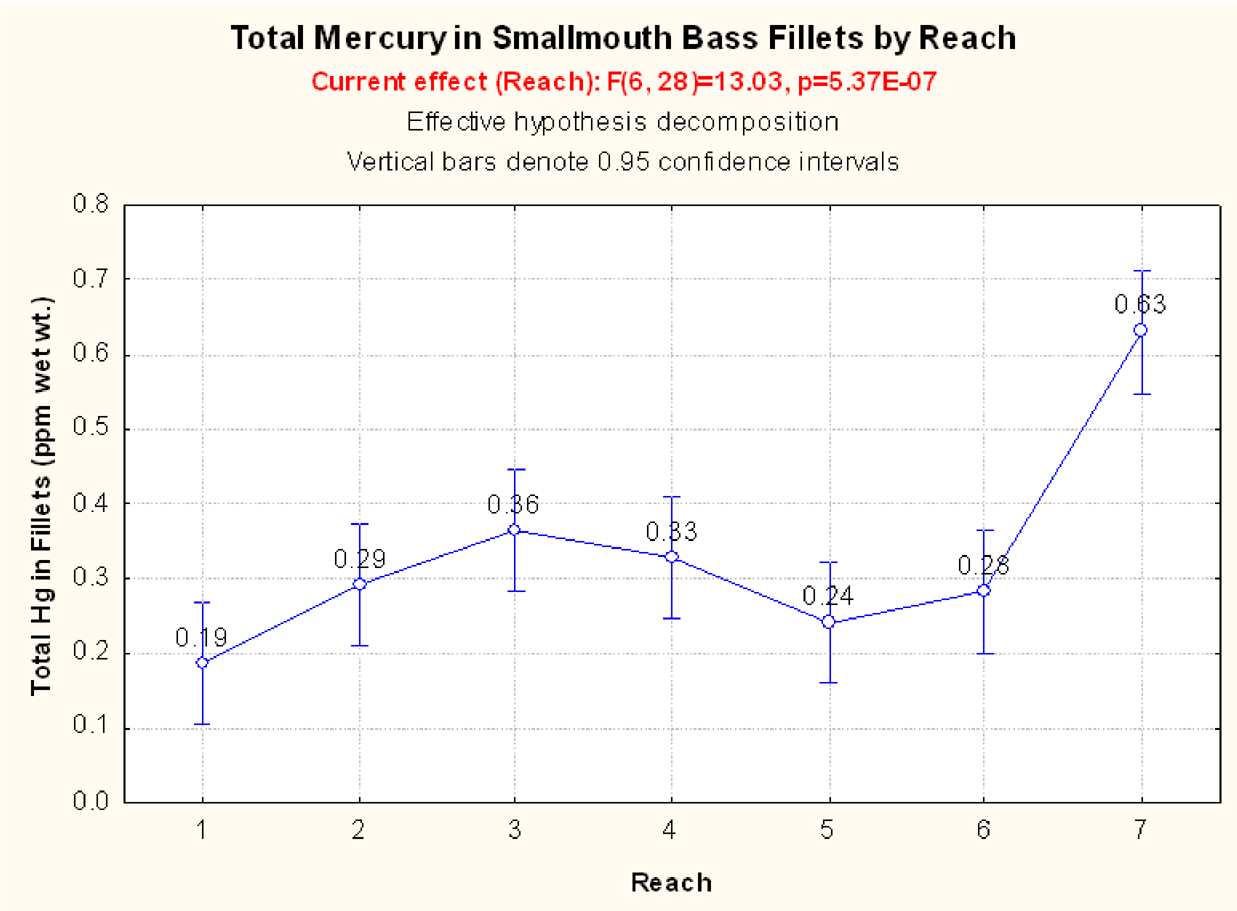

Figure 31. ANOVA of Total Mercury in Smallmouth Bass Fillets by Reach

For total mercury in smallmouth bass fillets Reach was highly significant (p= 5.37E-07) (Figure 31). Table 16 summarizes the post-hoc pair-wise comparison by Reach of least square means of total Hg in smallmouth bass fillets.

Table 16. Statistical Comparison by Reach of Total Mercury in Smallmouth Bass Fillets (Fisher's Least Significant Difference Post-Hoc Test of Least Square Means)

Least Square Means	0.19	0.29	0.36	0.33	0.24	0.28	0.63
Reach	1 2	3	4	5	6	7	
1		0.07	**3.63E-03**	**0.02**	0.33	0.10	**1.34E-08**
2			0.20	0.54	0.38	0.86	**1.72E-06**
3				0.51	**0.04**	0.15	**5.94E-05**
4					0.14	0.43	**9.43E-06**
5						0.48	**1.65E-07**
6							**1.08E-06**

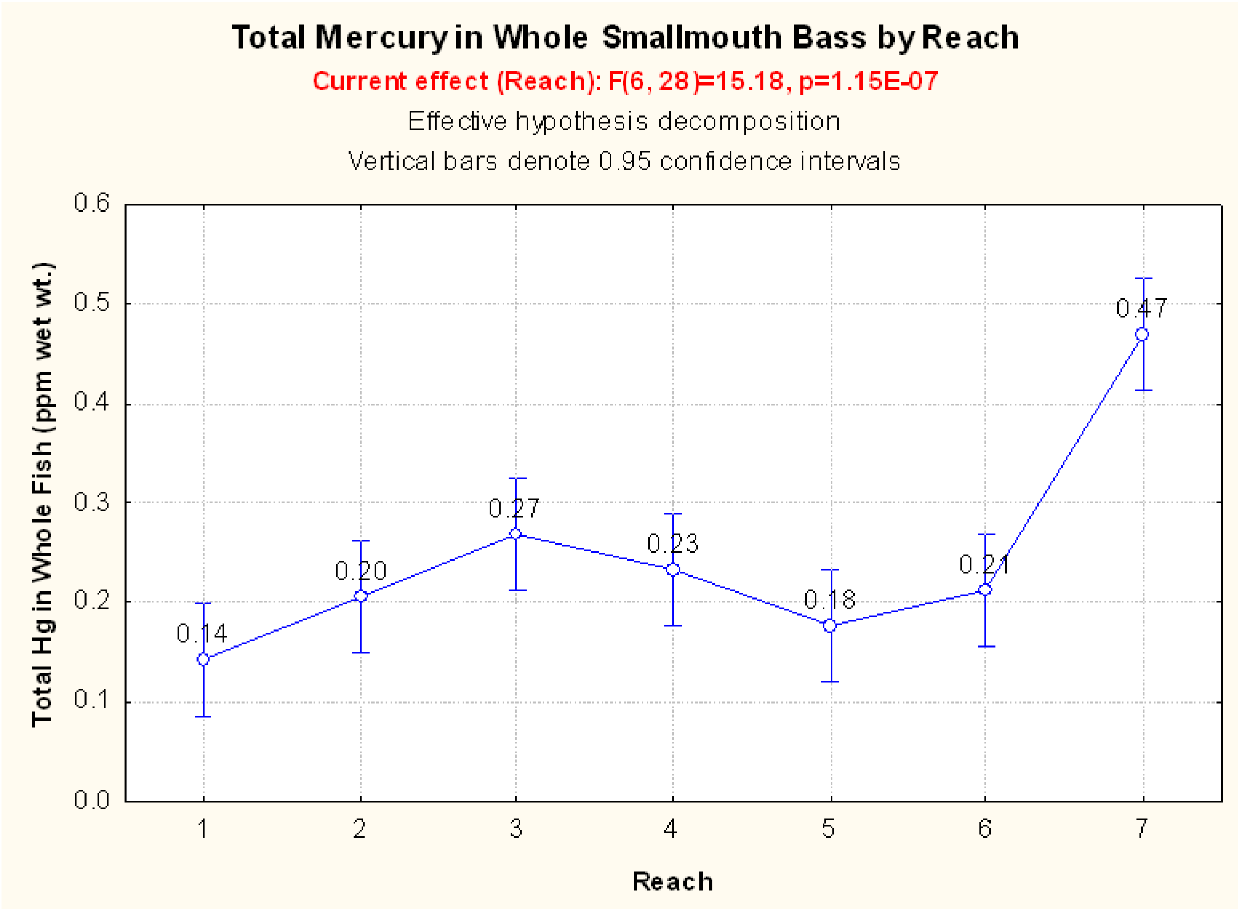

Figure 32. ANOVA of Total Mercury in Whole Smallmouth Bass by Reach

For total mercury in whole smallmouth bass Reach was highly significant (p= 1.15E-07) (Figure 32). Table 17 summarizes the post-hoc pair-wise comparison by Reach of least square means of total Hg in whole smallmouth bass.

Table 17. Statistical Comparison by Reach of Total Mercury in Whole Smallmouth Bass (Fisher's Least Significant Difference Post-Hoc Test of Least Square Means)

Least Square Means	**0.14**	**0.20**	**0.27**	**0.23**	**0.18**	**0.21**	**0.47**
Reach	**1 2**	**3**	**4**	**5**	**6**	**7**	
1		0.12	**3.04E-03**	**0.03**	0.39	0.08	**3.85E-09**
2			0.11	0.49	0.47	0.84	**2.19E-07**
3				0.36	**0.02**	0.16	**1.79E-05**
4					0.16	0.62	**1.42E-06**
5						0.36	**3.35E-08**
6							**3.72E-07**

2.12.2 Yellow Perch

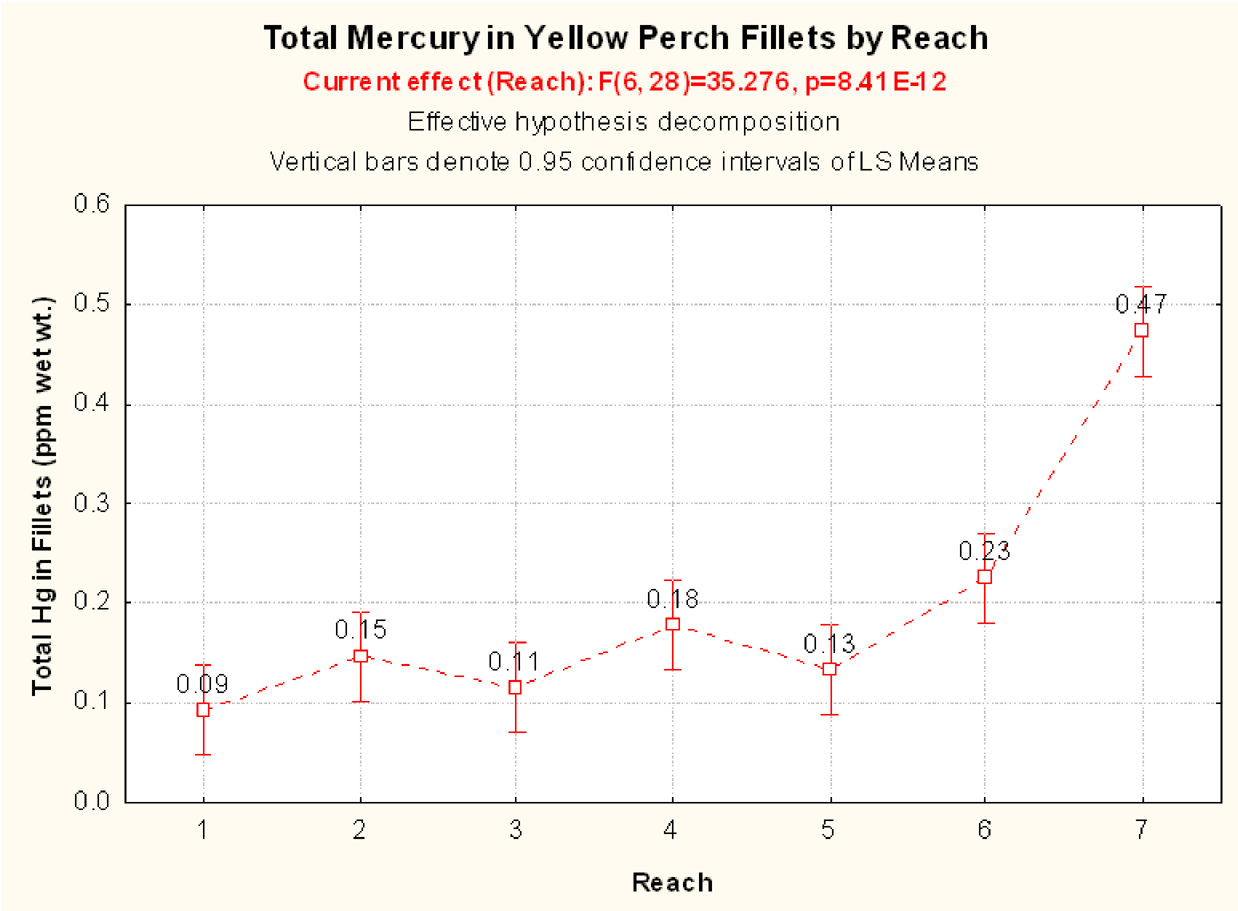

Figure 33. ANOVA of Total Mercury in Yellow Perch Fillets by Reach

For total mercury in yellow perch fillets Reach was highly significant (p= 8.41E-12) (Figure 33). Table 18 summarizes the post-hoc pair-wise comparison by Reach of least square means of total Hg in yellow perch fillets.

Table 18. Statistical Comparison by Reach of Total Mercury in Yellow Perch Fillets (Fisher's Least Significant Difference Post-Hoc Test of Least Square Means)

Least Square Means	0.09	0.15	0.11	0.18	0.13	0.23	0.47
Reach	**1 2**	**3**	**4**	**5**	**6**	**7**	
1		0.10	0.48	**0.01**	0.21	**1.96E-04**	**8.82E-13**
2			0.32	0.29	0.67	**0.02**	**2.89E-11**
3				**0.05**	0.57	**1.30E-03**	**3.58E-12**
4					0.15	0.15	**3.07E-10**
5						**0.01**	**1.17E-11**
6							**1.07E-08**

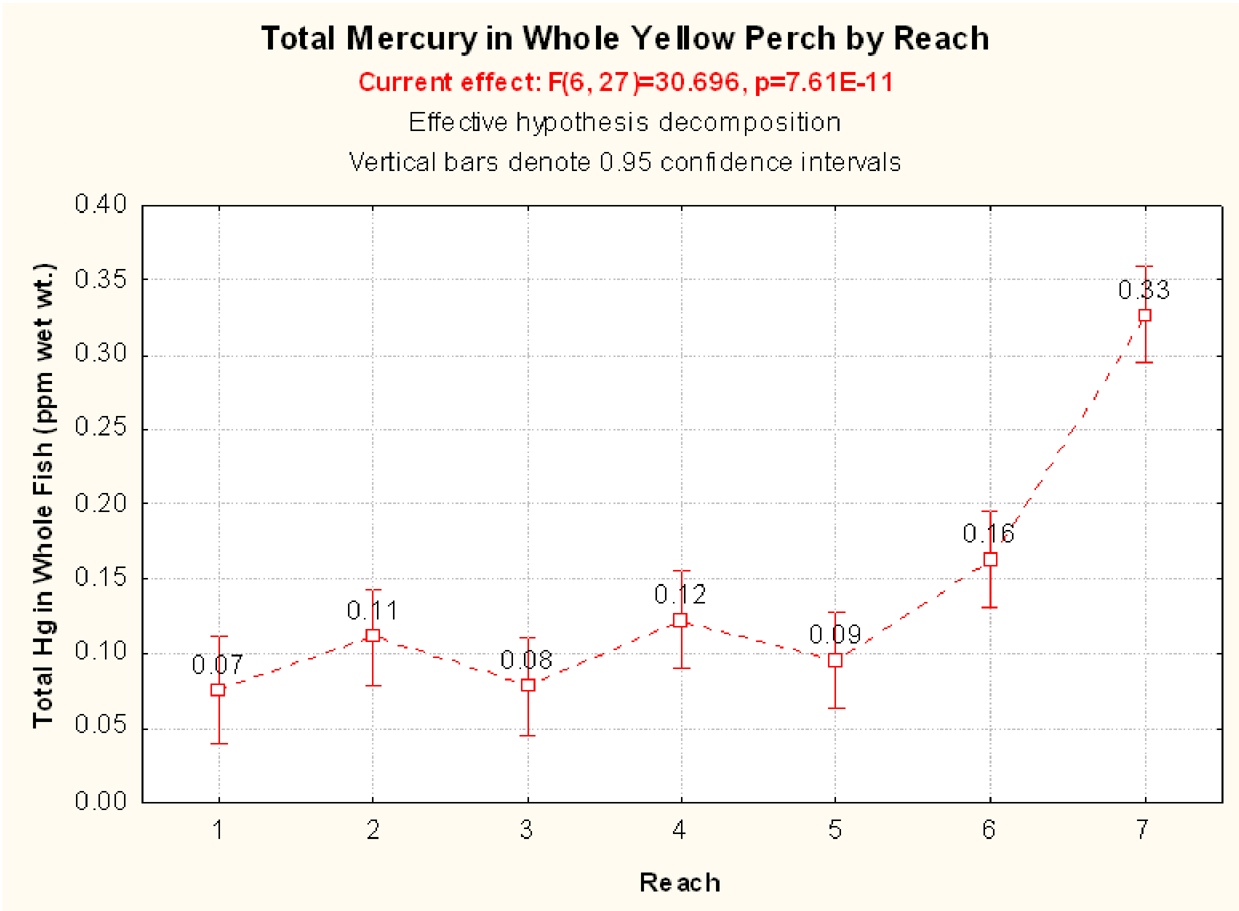

Figure 34. ANOVA of Total Mercury in Whole Yellow Perch by Reach

For total mercury in whole yellow perch Reach was highly significant (p= 7.61E-11) (Figure 34). Table 19 summarizes the post-hoc pair-wise comparison by Reach of least square means of total Hg in whole yellow perch.

Table 19. Statistical Comparison by Reach of Total Mercury in Whole Yellow Perch (Fisher's Least Significant Difference Post-Hoc Test of Least Square Means)

Least Square Means	**0.07**	**0.11**	**0.08**	**0.12**	**0.09**	**0.16**	**0.33**
Reach	**1 2**	**3**	**4**	**5**	**6**	**7**	
1		0.14	0.89	**0.05**	0.40	**9.51E-04**	**3.62E-11**
2			0.15	0.60	0.48	**0.03**	**2.82E-10**
3				0.06	0.46	**7.71E-04**	**1.31E-11**
4					0.23	0.08	**9.09E-10**
5						**0.01**	**6.15E-11**
6							**6.43E-08**

2.12.3 White Sucker

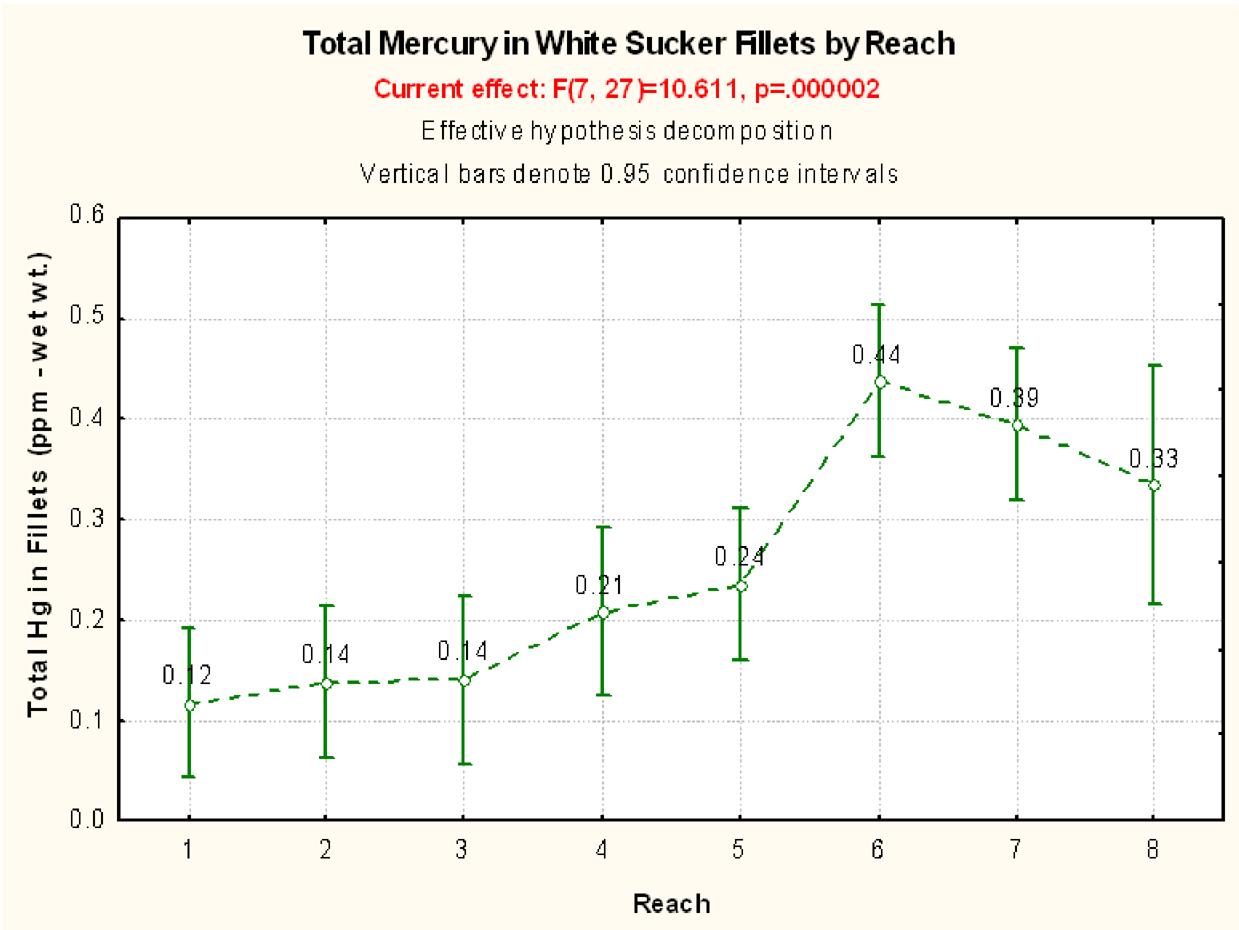

Figure 35. ANOVA of Total Hg in White Sucker Fillets by Reach

For total mercury in white sucker fillets Reach was highly significant (p= 2.37E-06) (Figure 35). Table 20 summarizes the post-hoc pair-wise comparison by Reach of least square means of total mercury in white sucker fillets.

Table 20. Statistical Comparison by Reach of Total Mercury in White Sucker Fillets (Fisher's Least Significant Difference Post-Hoc Test of Least Square Means)

Least Square Means	0.12	0.14	0.14	0.21	0.24	0.44	0.39	0.33
Reach	1 2	3	4	5	6	7	8	
1		0.69	0.67	0.11	**0.03**	**1.35E-06**	**1.25E-05**	**3.83E-03**
2			0.95	0.22	0.07	**3.84E-06**	**3.65E-05**	**0.01**
3				0.27	0.10	**1.09E-05**	**9.20E-05**	**0.01**
4					0.62	**2.71E-04**	**2.15E-03**	0.08
5						**5.73E-04**	**4.94E-03**	0.16
6							0.41	0.14
7								0.39

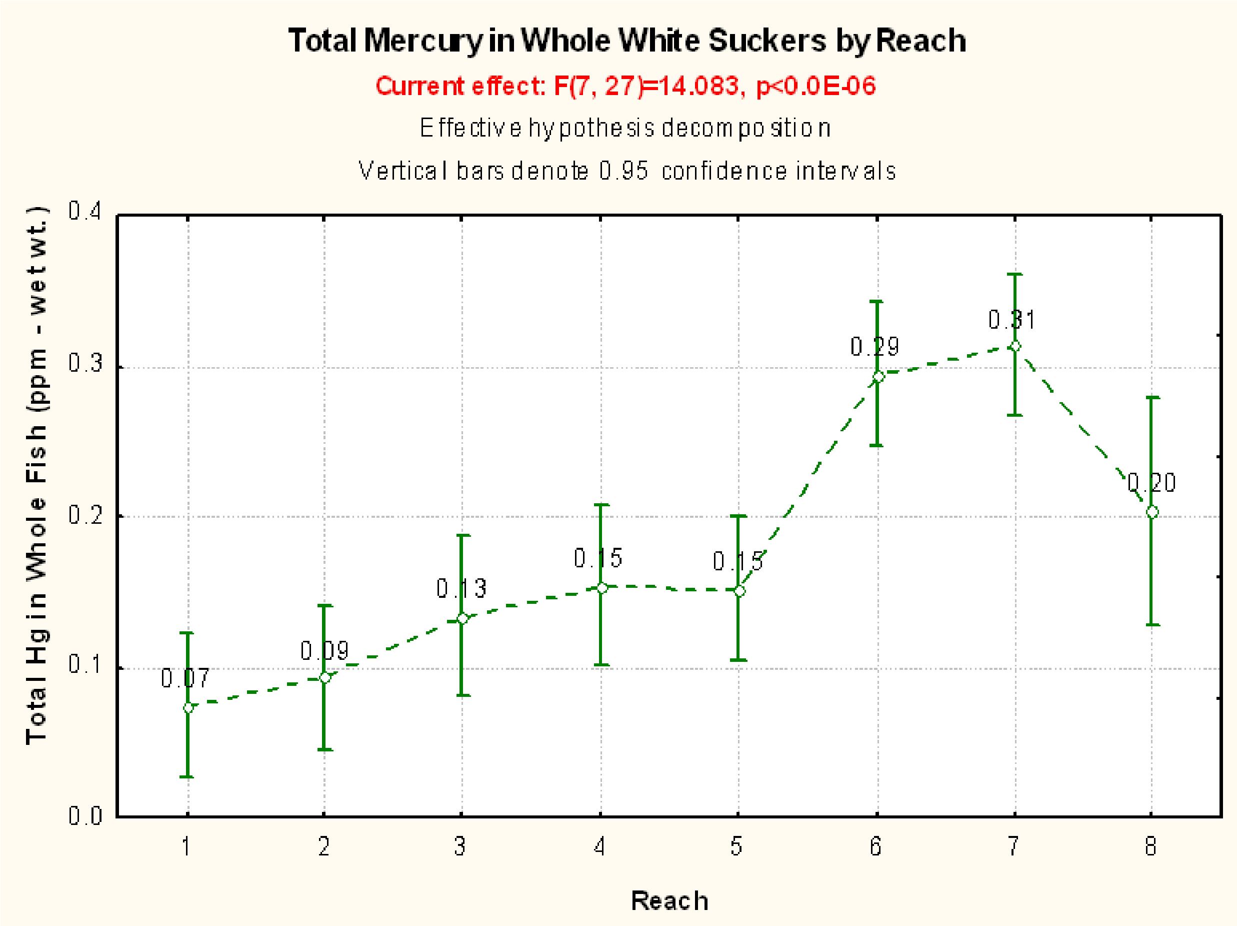

Figure 36. ANOVA of Total Hg in Whole White Suckers by Reach

For total mercury in Whole white suckers Reach was highly significant (p= 1.52E-07) (Figure 36). Table 21 summarizes the post-hoc pair-wise comparison by Reach of least square means of total mercury in whole white suckers.

Table 21. Statistical Comparison by Reach of Total Mercury in Whole White Suckers (Fisher's Least Significant Difference Post-Hoc Test of Least Square Means)

Least Square Means	**0.07**	**0.09**	**0.13**	**0.15**	**0.15**	**0.29**	**0.31**	**0.20**
Reach	**1 2**	**3**	**4**	**5**	**6**	**7**	**8**	
1		0.57	0.10	**0.03**	**0.02**	**3.19E-07**	**7.43E-08**	**0.01**
2			0.25	0.09	0.08	**1.42E-06**	**3.18E-07**	**0.02**
3				0.59	0.60	**8.20E-05**	**1.90E-05**	0.13
4					0.97	**3.80E-04**	**8.91E-05**	0.27
5						**1.76E-04**	**3.74E-05**	0.25
6							0.57	**0.05**
7								**0.02**

2.12.4 Total Mercury - ANOVA Summary

All three species had significantly higher levels of total mercury in fillets and whole fish in Reaches 6 and 7 than in most lower Reaches. The pattern of total mercury in fillets and whole fish differed by species (Figures 26 and 27; Tables 14 and 15).

Smallmouth bass fillets and whole fish total mercury in Reach 7 were significantly higher than all other Reaches (Figures 31 and 32; Tables 16 and 17). Reaches 3 and 4 were significantly higher than Reaches 1, 2, and 5 for both fillets and whole fish in smallmouth bass.

Yellow perch fillets and whole fish were significantly higher in Reach 4 than in Reaches 1 and 3 (Figures 33 and 34; Tables 18 and 19). Reach 6, for both fillets and whole fish were significantly higher than all Reaches, except Reach 4. Reach 7 for both fillets and whole fish were significantly higher than all other Reaches.

White sucker fillets and whole fish in Reach 5 were significantly higher than Reach 1 (Figures 35 and 36; Tables 20 and 21). Reach 4, in whole fish, was also higher than Reach 1. Reaches 6 and 7 were significantly higher than Reaches 1-5 in both fillets and whole fish. Reach 8, in white sucker fillets, had a very small sample[34], however, it was still significantly higher than Reaches 1, 2, and 3. For Reach 8 whole white suckers were significantly higher than Reaches 1 and 2 and lower than Reaches 6 and 7. In whole white suckers Reaches 4 and 5 were significantly higher than Reach 1.

[34] The Reach 8 sample consisted of only two white sucker composites.